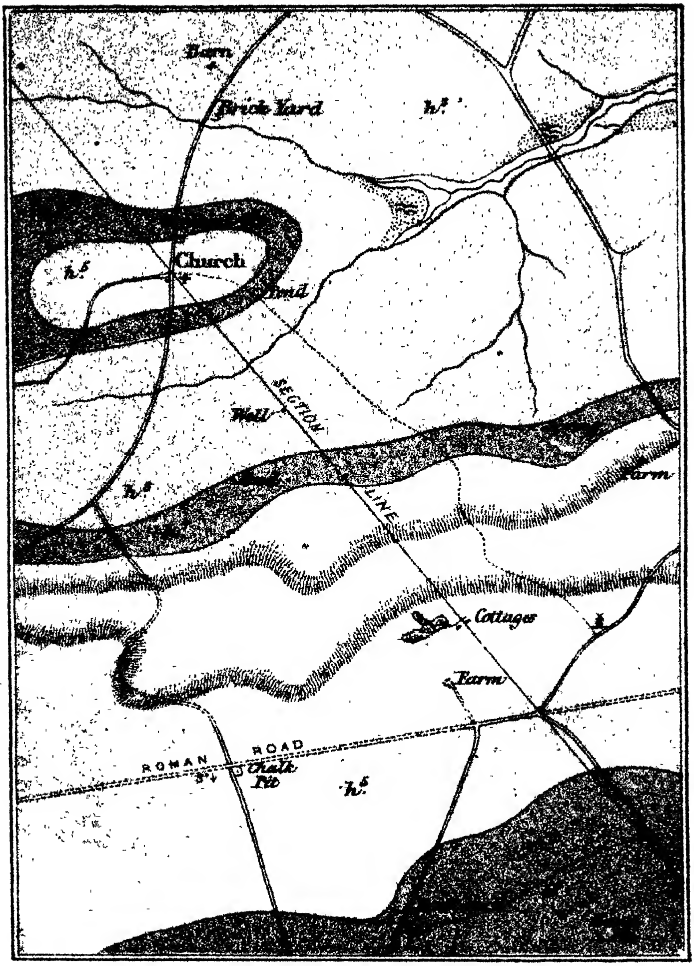
FRONTISPIECE.

Scale 1½ inches to 1 mile.



h^8 GAULT
h^5 CHALK
h^4 UPPER GREENSAND
i^2 READING BEDS
ALLUVIUM
BRICK-EART
GRAVEL

A

TEXT BOOK OF FIELD GEOLOGY,

BY

W. HENRY PENNING, F.G.S.,
GEOLOGIST, H. M. GEOLOGICAL SURVEY OF ENGLAND AND WALES.

WITH A SECTION ON

PALÆONTOLOGY,

BY

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SECOND EDITION,
Revised and Enlarged,
WITH ILLUSTRATIONS AND COLOURED PLATE.

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PREFACE TO SECOND EDITION.

In the preface to the first edition I stated that my first idea, in regard to a work of this kind, was to publish 'a few plain instructions for drawing geological boundary-lines, a practical matter somewhat neglected although of considerable importance. But there is an almost imperceptible transition from mapping rocks which appear at the surface of the earth, to tracing those that are beneath; and from defining the extent of a formation, to the determination of its history, as expressed in its lithological character and fossil remains. The idea therefore, while being realised, expanded to much beyond its original dimensions.

'There are so many subjects of which a knowledge is an advantage in geological surveying, that it is difficult to say what ought not to be included in a book on Field Geology.' And as a lenient critic of the first edition truthfully observed, 'Geological surveying is an art which for its successful performance requires some natural aptitude, a considerable knowledge of the principles and results of geological science, careful training

and much practice. Hitherto, the methods employed have been handed down by tradition only, and no work has existed to which an outsider or foreigner could refer for an exposition and illustration of them.' Another remarks that the young student 'may be familiar enough with the latest geological theories, and may have long lists of fossils at his fingers' ends; yet he may be utterly embarrassed the first time he attempts to trace the boundary-line of a formation, or even to determine approximately the age of the rock beneath his feet.'

The objects primarily aimed at have been kept steadily in view; their scope having been, advisedly, neither diminished nor extended. These are: first, to include such instructions as are essential to the working out, either for scientific or practical purposes, the geology of a district, by the determination of its rocks, their extent, relations, comparative age, and economic productions; secondly, to exclude all descriptions and explanations of the principles of Geology as a science, which would be out of their proper place in a field-guide, and which meet with many more able exponents in the authors of our geological manuals.

My colleague, Mr. Jukes-Browne, has been good enough to revise and extend his section on Palæontology, and to furnish entirely new lists of characteristic fossils, which will be found of much value in the identification of geological horizons. The length of the lists was unavoidable, as he was anxious to make them as complete as possible up to the present time; in this endeavour, and in their final revision, he has received the valuable

assistance of Mr. R. Etheridge, whose kindness he desires to acknowledge.

The new rules for finding the true dip, from two apparent dips or from three points on an outcrop, have been extended in accordance with suggestions (for which I feel greatly indebted to those whose names are given in the text) made in letters to the editor of the 'Geological Magazine.'

I have much pleasure also in acknowledging, with my best thanks, the value of many other suggestions and consequent improvements in the work, kindly sent to me by Professors T. Rupert Jones, T. G. Bonney, J. Prestwich, F. W. Rudler, and G. A. Lebour, and by Messrs. W. Whitaker, H. B. Woodward, F. Drew, and W. Keeping.

W. HENRY PENNING.

GRANVILLE HOUSE,
FINSBURY PARK, LONDON.

November, 1879.

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INTRODUCTION.

It may fairly be claimed for Geology that its advance has been more rapid than that of any other science. From the time of William Smith, the Father of English Geology, until now, the number of those who take interest in the subject has been steadily increasing. Every year sees the birth of some new periodical devoted to Geological Science; every list of new books is sure to contain the name of one, or more, bearing directly, or indirectly, on the questions with which it deals; and it possesses already a most comprehensive literature. It plays a prominent part in University and other public examinations, where, a few years since, it was all but unknown; and it guides, as it ought to guide, the direction of mining and other practical operations. With many, the study is taken up as an amusement or a pastime, and is found to possess a fascination peculiarly its own; it opens up to the more philosophical student a fair field of investigation; and it presents to all, many interesting physical problems for thought and speculation.

As the number of geological students increases, the

greater is felt to be the need of a Manual which shall teach the practical methods of geological research and observation. As a rule the manuals of Geology, although excellent guides to a theoretical knowledge of the science, do not sufficiently describe the actual methods of procedure in the field, and of reduction of the results to a practical form.

Without such proper methods much time is wasted, many results that otherwise would have been valuable are entirely lost, and the student finds that his labours do not yield a proportionate amount of beneficial knowledge. This work has been prepared with the view of embodying, in a small compass, practical directions and suggestions which are to be found here and there only in more important works. The main object of the author has been to bring them, with some additions, which are the result of his own experience, into a form which shall be at the same time instructive, portable, and adapted to special reference.

To make a series of drawings that shall show the geological structure of any district, it is not sufficient to be versed in theoretical geology, or even to be able, when visiting a quarry, to distinguish Limestones, Sandstones and other rocks, or to determine that they belong to any particular Formation. Their boundaries must be traced, to show the area that each occupies, and the angle at which they dip beneath the surface must be ascertained. When these points are determined in regard to a series of strata, and laid down on paper, they form a geological Map, or surface projection, and, by the aid of notes, a geological Section, or vertical projection, can be constructed therefrom which shall show

the underground extension of the rocks, their thickness and their relative positions. The kind of rock of which any bed, or series of beds, consists, is determined by its general appearance, and by simple tests, in the field; or if necessary, more complicated ones applied to detached specimens at home. By these means, and by the determination of the Fossils collected from such bed, or series of beds, it may be assigned to its position as belonging to a certain formation, or possibly, even to a definite horizon in such formation.

Therefore, to obtain an accurate knowledge of the structure of a district, to represent and describe its geological features, and to be able to generalise therefrom, four distinct and different, although intimately connected, operations have to be performed. The strata which crop out at its surface must be traced, and their boundary laid down upon the map—the dip (if any) and the underground continuation of the beds worked out—the character, peculiarities, and geological age of the rocks ascertained—and their fossil contents discovered, determined and classified. Each will be treated of separately as far as possible, under one of the following heads:—

1. Geological Surveying.
2. „ Sections.
3. Lithology (*Determination of Rocks*).
4. Palæontology („ „ *Fossils*).

The directions given in each Part are simple and elementary, assuming the student to possess a fair book-knowledge of the science, of its principles, of

the sequence of the various systems, formations and groups, and of the general succession and range of fossil plants and animals. By giving simple examples of the methods employed, the chances of confusion or misapprehension are greatly lessened; at the same time, these admit of suggestive hints being inserted, which indicate, rather than describe, the more detailed and complicated operations and calculations.

Geological maps and sections are incomplete unless they include all the available information regarding the economic products of the area surveyed; therefore some notes are given on the more common Minerals, Metals and their Ores, their mode of occurrence, and the methods adopted for their discovery and utilisation. A brief description is also inserted of the mode of occurrence of those rocks which do not follow the general laws of stratification and superposition. These are the eruptive and intrusive rocks and the glacial deposits, which require a somewhat different method of ascertaining and showing their extent and their relations. A short sketch is added of the phenomena of deep-seated springs, including the practical application of geological surveying, in the important question of water-supply from Artesian wells.

PART I.

GEOLOGICAL SURVEYING.

CHAPTER I.

SURVEYING, AND INSTRUMENTS.

Maps—Contour Maps—Compass and Protractor—Hammer, Pick, Spud, &c.—Scales—Tracing Boundaries—General Propositions.

Maps.—A geological map is one which defines the area occupied by the denuded edge, or upper surface, of each formation, where it comes to the level of the ground. To accurately construct such a map, therefore, every part of the area geologically surveyed must be more or less minutely examined. It is very essential, in tracing and drawing its geological boundary-lines, to have as good a map as possible of the district to be surveyed. One that is not tinted, and not closely covered with the names of places, is to be preferred, but on which such prominent objects as churches, windmills, and so on, are shown with fair topographical accuracy. The physical features should be rendered as distinct as may be, by the insertion of all rivers, brooks and water-courses; if

there be hill-shading, drawn with even an approach to accuracy, it will be an improvement; and heights above the sea-level given in figures here and there are a great advantage. Maps drawn to a scale of one inch to a mile will generally be found the best for the purpose; while sufficiently large to admit of the main features being correctly shown, a sheet representing many square miles can be carried and referred to without inconvenience. Where great accuracy is required, for instance in the out-crop of Coal-seams, it is well to have maps drawn on a six-inch scale, although they may be in some respects inconveniently large. For the plain spaces between road- and hedge-lines, admit of the frequent notes, necessary in such cases, being written on the map itself, instead of in a book specially provided; no trifling advantage when the size of the map to be carried is taken into consideration. The one-inch maps of the Ordnance Survey, especially those issued during the last few years, are as good as any; in choosing copies, those should be selected which are clear and distinct as regards the engraved lines, but which are light rather than dark impressions.

> *Note.*—All maps are laid down on the paper with reference to the *true meridian,* the proper allowance having been made in plotting them from compass bearings for the magnetic variation. At the present time the needle points, in these islands, about 18° 45′ West of due North.

The following table, compiled from the note given below, shows, within a few minutes, the variation of the compass for the present and five succeeding years. The odd minutes and seconds may very well be ignored

in geological surveying, as the compasses generally used for that purpose are not finely divided. *

Year.			Magnetic Variation.
1879	-	-	18° 45′ W.
1880	-	-	18° 30′ „
1881	-	-	18° 30′ „
1882	-	-	18° 15′ „
1883	-	-	18° 15 „
1884	-	-	18°

It is often found convenient to cut up the maps into quarters, or smaller divisions, and to mount them upon linen, so that they may be folded to fit into a case or to be carried in the pocket. The linen is laid on a flat wooden table or bench and thoroughly wetted all over, a process under which it shrinks considerably. The pieces of map are then pasted on the back, as required, each piece being allowed to remain a few minutes for the paste to soak into the paper, which will be swelled by the dampness. Commencing at one corner, the slips

* Hydrographic Department,
Admiralty, S.W.

FROM REPORT TO BOARD OF VISITORS TO GREENWICH OBSERVATORY.

Mean Value of the Declination or Variation of the Compass.

1877 - - 18° 57′ W.

Annual *decrease* 8′·3 (being the mean value of the secular change during the last ten years). This mean value will probably serve also for the next five years, as a means of obtaining the mean value of the variation for each year included.

are then laid in turn upon the linen, and the superfluous paste is squeezed from under them by pressing every part, with a cloth, outwards from the centre. Care must be taken to arrange the pieces in line by means of a straight-edge, and to leave between them sufficient space, about an eighth of an inch, for folding. In drying gradually the paper will have a tendency to shrink and the linen to expand; owing to this action the paper will be kept in a state of tension, and will remain with a smooth, level surface. Maps are mounted whole in a similar manner; the edges should in neither case be trimmed until perfectly dry.

Contour Maps.—Some maps have marked on them certain lines, the meaning of which it is well to clearly understand, and which are called 'contour lines.' These lines convey at a glance, to the eye accustomed to them, the physical geography, or the actual shape, of a tract of country, its hills and valleys, its precipices and ravines; not merely in a sketchy or approximate form, but with heights and depths taken from actual admeasurement. For a contour line runs through all the points at which a perfectly horizontal plane, at a given height, would intersect the surface of the ground; or in other words, if the land were covered with water to a certain height, the margin of the water would be exactly represented by a contour line drawn at the same elevation. These lines are shown for every 10, 25, 50, or 100 feet, according to the scale of the map and the degree of accuracy required. In geological surveying they are of assistance in the drawing of boundary lines, whether of horizontal or inclined strata, in ascertaining heights, with accuracy where they run, and between them by estimation. Ob-

served in relation to boundary lines, the contours indicate the direction, and in some measure the amount, of dip of the beds, and are otherwise useful in making various calculations.

Contours run in a V-like shape up the valleys, in lines more or less straight on flanks and ridges, and sweep round the outline of the hills; their variations are as numerous as the hills themselves, but these kinds of form prevail in all. It is but seldom, however, that a valley presents a straight line, it follows rather a serpentine course; therefore a contour, at or near its entrance, would be like a V with both its sides slightly curved in the same direction. Lines thus curved look better, whether as contours or geological boundaries, than they do with their sides symmetrical, and are also much more true to nature. (See some remarks on, and illustrations of, this subject in Sir Charles Lyell's 'Students' Elements of Geology.')

Compass and Protractor.—It frequently happens in the field, and especially in localities which are not familiar, that it is necessary to identify on the map one's exact locality. For this purpose the roads, fences, &c., shown thereon, do not always afford sufficient indication, but generally some object marked on the map, as a church or a windmill, can be recognised; a compass is then used for taking a bearing upon such object, distant or otherwise. An ordinary pocket-compass of fair size will suffice in most instances, and will give very nearly the position of the place at which it is used; but for greater exactness a prismatic compass is necessary. The latter is not quite so easily carried as the pocket-compass, although the small prismatic now made and

fitted in sling-case is very portable; its use, however, involves the carrying of a protractor for plotting the result of an observation.

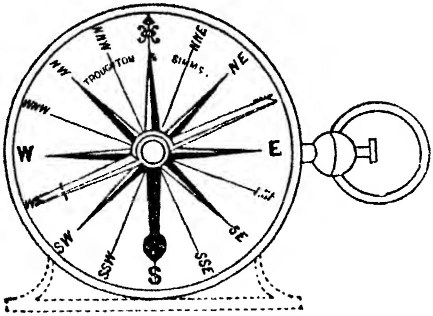

Fig. 1. Compass and Clinometer.

The pocket-compass (fig. 1) generally has its circumference divided into 16 parts—the four main divisions representing the 4 cardinal points, the 4 intermediate dividing the cardinals, and 8 others sub-dividing the spaces between the cardinal and intermediate points, as N.N.E., and so on.

To determine a locality, the instrument, with the needle set free, must be held, perfectly level, between the observer and the distant object on which he intends to take a bearing. It must be turned steadily round until the needle comes to rest nearly 20 degrees (18° 45′) on the left side, or West, of North.* At the same instant the eye, being carried from the centre of the compass to the object and back again, will detect the point in the circumference exactly in line with the object. This point is perhaps N.E., half-way between N. and E.; this would be represented on the map by a line, in such

* See Table of Magnetic Variation, p. 7.

a position as to lie mid-way between two others, one vertical for N. and S., the other horizontal for E. and W. direction. A scale or pencil laid across the object on the map, in such mid-way position, affords a ready means of drawing a pencil-line that fairly corresponds with the bearing taken. If E.N.E. had been read off, half-way again between N.E. and due E. would give the direction; the same method applies equally to all the other points in the compass, anything between them being read off, and laid down by estimation. The observer is situated on the line thus found, at some point which has next to be determined. This is done by taking a similar observation on another object, as nearly as may be at right angles to the first line, which gives a second line crossing it at a point representing the required position.

The prismatic- varies from the pocket-compass in having its circumference divided into 360 degrees, instead of into cardinal and intermediate points; and in being provided with sights for taking more accurate observations. The needle carries with it a nicely-balanced card on which the divisions are marked, the figures thereon being reversed so that the prism (which inverts the rays passing through it) presents them to the eye in their proper position. The card is sometimes so attached to the needle that proper allowance has been made for magnetic variation. (See Note, p. 6.)

To take a bearing, the needle must be liberated, the vertical wire erected, and the prism pulled up to suit the vision of the observer. The instrument is then held up to the eye, being kept as level as possible in the hand, and directed to the object from which the

bearing is being taken, until the card shall have gradually ceased to revolve. The division then seen immediately beneath the vertical wire records the number of degrees subtending the angle contained between the line of bearing and the true N. and S. meridian, if allowance has been made for variation, in the attachment of the needle to the card. If this has not been allowed for, a deduction of 18° 45′ must be made from the number of degrees read off, before the bearing is plotted.*

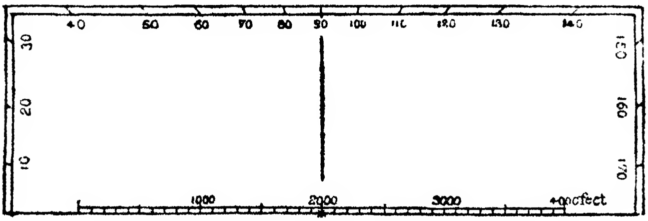

Fig. 2. Protractor, upper side (half size).

The number of degrees count to the right of due N.; thus E. reads 90°, S. 180°, W. 270°, and N. itself 360°, the complete circle. Therefore in plotting the line of bearing, the protractor (figure 2) must be laid on the map to the *right* of the object upon which the bearing was taken, the centre of the semi-circle which it represents resting directly upon it, and the inner edge being parallel (as nearly as the eye can judge) with the margin of the map—that is, due N. and S. A point is now marked on the paper at the number of degrees corresponding with the reading of the compass, and a line drawn through this point and the object gives the first bearing. A second line is then found to cross the first,

* See Table of Magnetic Variation, p. 7.

the same as in the example given for the pocket-compass; the nearer the angle between them is to a right angle the greater the accuracy of the result.

Note.—As the protractor represents but one half of the circle, it will be necessary when the number of degrees read off exceeds 180 (the total shown thereon) to plot that number and begin again—or, what is the same thing, to deduct 180 from the degrees indicated and commence from the other end, that is, with the protractor placed on the *left-hand* side of the object.

It sometimes occurs that one bearing only is sufficient for the purpose; for instance, when the spot is situated on a line of road or fence shown on the map, but with nothing to show its exact position upon that line. Another and a ready method of spotting one's locality, where there is no lack of landmarks, is to place on the ground a stick, or the handle of a hammer, with one end directed to some known object; then to look along the stick from its other end and note the object with which, or near to which, it is in line. This gives a fair bearing in one direction, and if it be crossed by another, as with the compass, the position found on the map will not be far wrong.

Hammer, Pick, Spud, &c.—For drawing geological boundary-lines, it is necessary to have at hand some means of ascertaining what strata come up to the surface, in any locality that is to be geologically mapped. There is always, or with very rare exceptions, a depth of surface-soil varying from two or three inches to two feet or even more, and beneath this is frequently found a subsoil, consisting of the disintegrated upper

portion of the rock on which it rests. To ascertain the kind of rock, these, or at all events the former, must be penetrated, where no natural or artificial sections are to be discovered.

Almost every one who follows geological pursuits has a hammer to suit his individual fancy, and so long as it is capable of breaking up a good-sized stone its fashion is immaterial. But it should have an even face, square by preference, of steel welded to an iron head, and tempered to stand a good blow without receiving fracture or indentation. For geological surveying it will be found convenient to have the tail-end of the hammer drawn out into a chisel-pointed pick, three or four inches in length, curving slightly downward, as shown in figure 3. The curve of the most useful pattern is struck from an outer radius of about eighteen inches, if for a hammer with a long handle; of about a foot if for one intended to be carried in a belt or pocket. With such a pick one

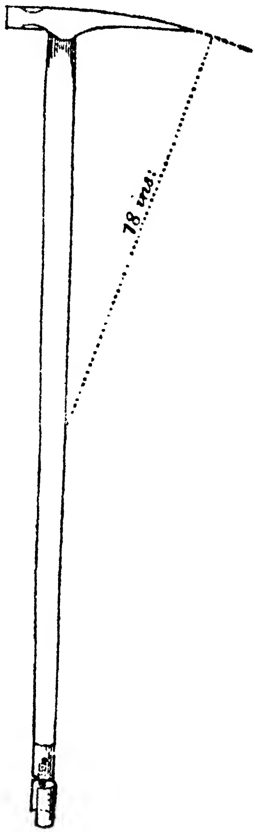

Fig. 3. Hammer, Pick, and Spud combined.

can easily dig down through a foot of surface soil or clear the face of clay and sand in pits, banks, and cuttings.

A fern-trowel, fitted in a leather case, is a very handy and portable implement for the same purpose, and especially so when searching in clay or sand for shells or other fossil organisms.

Some prefer boring to digging through the soil; this can be done by a gouge-like spud attached to the lower end of a stick or a long hammer-handle; it may be made either removable by a screw-joint or be permanently fixed. This spud, when pressed into the earth and screwed round, will make a hole from a foot to two or three feet deep, according to the hardness of the material, and bring up cores as specimens from the bottom. In figure 3 is represented a combined hammer, pick, and spud; with the latter unscrewed, the hammer does duty for a walking-stick; if the handle be made of lance-wood it need be neither heavy nor unsightly, and altogether it is as useful and portable a set of implements as can be carried by a Geologist.

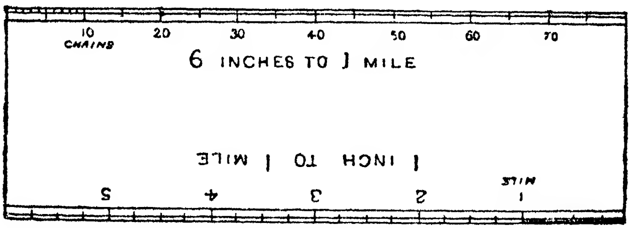

Fig 4. Protractor, under side as Scale (half size).

Scales.—For the purpose of measuring distances on the map, a scale is required, the most useful size being

six inches long. The carrying another instrument may be saved by having the reverse side of the protractor (figure 2) divided, for use with the six-inch maps, on the one edge into 80 parts, each part representing a chain on the scale of six inches to a mile. The other edge, for use with the one-inch maps, may be divided into inches, and these into 40 parts, each representing two chains on the scale of one inch to a mile; smaller subdivisions are too minute (figure 4). The otherwise plain edge (on the side used as a protractor) may with advantage be divided, for a part of its length, into feet, on the scale of six inches to a mile; it will be serviceable for plotting, or measuring from, sections (figure 2). A useful scale for enlarged sections, or other details, is one of 40 feet to an inch, as used in the Vertical Sections published by H. M. Geological Survey.

Tracing Boundaries.—If by any means, as by boring or digging holes, the strata at the surface of any area were to be examined at every hundred yards, and if the varying results were shown by different colours, a geological map would be roughly presented. But a map thus made would be an approximation only, for there would still remain to be shown the exact position between the borings where the lines of division run. In the following chapters it is fully explained, by aid of examples, how such boundary-lines may be discovered, traced, and accurately represented on the map to be geologically coloured.

By the term 'boundary-lines,' is meant those which bound a formation, which describe its lower margin,

and, in fact, indicate its extreme occurrence in any direction. Its upper edge, where it first appears at the surface, is called its 'line of outcrop,' and this, of course, corresponds to the boundary-line of the overlying formation.

If a certain set of fields on one side of any road, fence, or brook depicted on the map, were entirely on one formation, and another set of fields, on the opposite side, were entirely on another formation, then the engraved line would answer also for that of the geological boundary. But it seldom happens that the purely arbitrary lines of a road or fence follow the intricate windings of a natural division of the rocks. With a brook, which follows a natural and not an artificial course, the case is somewhat different, and it is frequently found that brooks and water-courses do work their way along such planes of separation.

The first point to be ascertained, in surveying a district, is the nature of the rocks which come to the surface, so that the extent of ground occupied by each may be defined; the second, is the exact position of the boundary-lines between them. The relation of the rocks, that is their position in regard to each other, may be discovered during the survey, by their being seen in juxtaposition in a quarry or other actual section. If the rocks are not so seen, their relation may be inferred from two or more sections so situated as to warrant the conclusion, although exhibiting no junctions of the beds. If no sections whatever are met with, it may then be worked out from the dip of the planes of division, calculated from the boundary-lines, when a sufficient length for the purpose has been

drawn. Such details as the thickness of the beds, their dip, and other stratigraphical characteristics, will also be collected during the survey, or can be worked out from the data then obtained, by the methods hereafter described. When sections occur, the lithology and palæontology will, at the same time, demand attention.

Almost every bank where the road is in cutting, and every ditch of even moderate depth, will yield evidence of the kind of rock beneath, after the fallen soil and rubbish have been cleared away. When picking into a bank, spudding at the side of a ditch, or cutting at the face of an exposed section, care must be taken to get at the actual stratum beneath the vegetable soil or fallen material. In the absence of ditches, trenches, and banks (and there are many bleak spots bare of all such useful aids), we must pick or bore through the surface soil; also examine its surface for weathered lumps of the rock worked up from below. We must look for the heaps of stuff thrown out from their holes by moles, rats and rabbits—these often afford useful hints in an obscure area—and last, but not least, we must accustom our eye to judge from the soil itself what is the rock which lies beneath it and from which indeed it has been derived.

All soil or mould has been produced, during the lapse of many ages, by the disintegration, arising chiefly from the action of rain, frost and other atmospheric influences, of the exposed surface of the strata which form the base or subsoil. It has been increased in depth by the annual growth and decay of vegetable matter, assisted by the apparently trifling, but still ceaseless, action of earthworms, working into and turning up the subsoil.

It is thus evident that the nature of the soil of a district must strictly depend on that of the subsoil from which it is directly derived; and as the strata, which in weathering have formed the subsoil, present many varieties, they give rise to subsoils and soils that differ in a corresponding degree. The subsoil and soil of any locality, situated on a formation of reasonable thickness, must partake of the nature of that formation, whether it be limestone, sand, clay, or any other rock.

The composition of soil is very variable, being thus dependent on that of the subsoil, by the decomposition of which it has been formed, and it bears to the subsoil a nearly constant relation. An average soil consists of silica, alumina, lime, magnesia, oxide of iron, small quantities of ammonia, carbonic acid, and alkaline and earthy salts, with a portion of decaying organic matter. The nature and fertility of the soil varies as these constituents are present in a greater or less degree, all being to some extent necessary for the proper development of plants, but some, in excess, are injurious to vegetable growth; for instance, soils containing much sulphate of iron are invariably unproductive.

A base of gravel or sand produces a light soil abounding in silica—that substance not unfrequently forming more than four-fifths of its whole weight—which varies from a fine sandy mould to a stony soil, as the particles of the gravel beneath are in size fine and uniform or coarse and irregular. Clay gives rise to a stiff, heavy, and sometimes tenacious soil, consisting to a considerable extent of alumina, and varying in quality and appearance perhaps more than that on other kind of rock, but being generally productive.

There are certain natural causes which modify, to some extent, the nature of soil; the results of the influence exerted by these causes being geologically small, but economically important. The heavier storms of rain remove particles of soil from higher to lower ground in appreciable quantity. The effects of this action are not very perceptible in a flat country; but where the surface is broken by hills and small valleys, accumulations, several feet thick, may often be seen. Also, where the downward progress of rain-wash on a hillside has been arrested by a fence, its result, after a few years, is very evident, in the ground being unduly higher on the upper than on the lower side. The annual growth and decay of vegetation is an important modifying cause so far as fertility is concerned. The plants that have lived and died upon the surface have all, minute as they are in many instances, performed a useful part by absorbing from the air carbonic-acid, water and ammonia, and yielding to the soil, by their decay, those substances which form its organic constituents. The proportion of decaying vegetable matter in soils is usually small—about one-fiftieth—but sometimes it is excessive, as in peat, and the soil is thereby rendered almost worthless for purposes of cultivation. The matter derived from animals living on, above, and beneath the surface, and from their ultimate decomposition, naturally contributes to the fertility of soil, to an extent perhaps much larger than is generally appreciated.

The local vegetation is a trustworthy guide, not only to the fertility of a soil, but also to its nature, therefore to that of the rocks from which it has been formed by disintegration. There are numerous trees, shrubs, and

small plants, which will grow only on retentive soils, others only on those which are light and porous; or, if they grow at all, it is in a feeble and starving manner. The oak is a good example of a tree which flourishes, and attains perfection, on clay; but has a stunted appearance, and decays prematurely, on light soil. A boundary-line might often be drawn, almost correctly, by being carried between the fine full-grown oak trees on the one side and the dwarfed ill-shapen ones on the other, in districts where argillaceous and siliceous rocks are contiguous. Fir-trees, on the other hand, grow freely in light sandy soils and on barren heaths, while on clay they make but a poor appearance. Quick-set and other hedges also, where untrimmed, will mark the distinction between soils; there is perhaps a sudden change in the character of their growth, being, on one side of a boundary-line, low and poor, on the other high and luxuriant.

Again, on limestone soils, common snails exist in evident abundance, with others that are rare or even unknown elsewhere; but on sands and clays which are not calcareous, and therefore yield no lime for the production of their shells, they are equally conspicuous by their absence. Partridges are much more numerous on light and sandy soils than on others, because there ants and ant-eggs, their favourite food, abound; for another reason, facility of burrowing, rabbits prefer, and are seen in greater number, in similar situations. On sandy tracts, and light soils generally, snakes may be frequently seen, but on clays they are comparatively unknown. These facts in Natural History are mentioned as a few out of many which are safe and inte-

resting auxiliaries in geological surveying, and which cannot fail to make impression on those who wander over the country in search of geological evidence, or who take any delight in exercising their powers of observation.

Farming operations also are a guide, not only in a direct manner, by the opening of drains, the clearing out of ditches, and the occasional turning up of the subsoil by the plough, but indirectly by the arrangement of fields and the methods of cultivation. An open tract, with large fields and few ditches, is generally (but not invariably) upon a light rather than a heavy soil; if ditches are numerous and the fields small, they are almost sure to be upon a retentive clay which requires much draining. Dairy farms are usually on clay; while calcareous and siliceous rocks yield soils generally used as arable land, and better suited to the higher modes of agriculture. Where meadows and ploughed fields are found in the same district, the pasture is generally on the clay and marsh land; the lighter soils, and calcareous clays where such exist, being best suited to the purposes of wheat-growing and general cultivation.

Then the shape of the ground will afford further indications of the kind of rock beneath, for the variations in hardness and dip of the rocks have given the form to the district in which they come to the surface. Precisely in inverse ratio to these conditions, have the agents of denudation worn them away; or, to put the proposition in another form, the prominent minor features of a district are in exact proportion to the power its rocks possess of resisting denudation. As dissimilar rocks thus make a change of feature along

their junction, a knowledge of the fact is of great service in drawing their lines of boundary. But it must be remembered that denudation will also obscure the minor features that it has made, for the rain-wash, which is the immediate result of sub-aërial erosion, will fill up the smaller hollows and lodge on projections.

The foregoing are general ideas which it will be well to have impressed on the mind, as in tracing a boundary-line a knowledge of their principles will yield immense assistance. In practice the ground must, of course, be gone over, and the actual line followed, for dip may change anywhere, and it often does so in places where it is least expected. Faults also may occur, and these interrupt suddenly the continuity of a line, and involve a fresh one of their own.

General Propositions.—The face of the earth not being flat, but here rising into hills and there sinking into valleys, all planes of division between the rocks, whether horizontal or inclined, must follow, at the surface where they emerge, a more or less winding course, directly corresponding with the form of the ground. In tracing the boundary-lines which represent, at the surface, these divisional planes, the three following propositions will afford material assistance:—

1. *The boundary-lines of horizontal strata exactly coincide with the contours.*

   We cannot fail to see that this must be the case, however uneven the surface of the ground may be at the outcrop.

2. *The boundary-lines of strata dipping towards a hill are less winding than the contours.*

   This is at once evident, if we consider that were the dip to be gradually increased until the strata became vertical, the lines of division would gradually approach, and finally become, parallel straight lines. Therefore, as the dip into a hill, so the line varies from the contour towards a straight line.

3. *The boundary-lines of strata dipping from a hill are more winding than the contours.*

   This is the reverse of Prop. 2, for were the dip increased until exactly equal to that of the surface slope, the planes of division would continue beneath the surface, and unless the slope increased, could not possibly form a line of boundary. But the proposition is true to this point only, for when the dip *exceeds* that of the slope in the same direction, the boundary-lines wind in a reverse way to the contours, and also begin to draw in towards a straight line, as the amount of the dip is increased.

1. Strata sometimes occur in a horizontal position, when it is evident from Prop. 1, if we can once determine a point through which the boundary of such a stratum passes, a contour drawn from this point will accurately represent the geological line.

2. Much more frequently we find strata dipping towards the higher ground from beneath which they have risen to the surface. This may, indeed, be considered the normal position of stratified rocks which now form dry land, as their dip has almost invariably

given the initial form to the hills above them. In this case all points at the same level on the line of strike must be also on the boundary, if its passing through one of them has been ascertained. A line through such points and resembling the curves of the contours, but flattened in proportion to the dip (Prop. 2), represents accurately the line required.

3. It is an exceptional occurrence for strata, at their outcrop, to dip with the slope of the ground. (They may rise with it from beneath higher ground, thus forming a 'dip-slope,' but such cases come really under Prop. 2.) When this does occur, the line of junction must be ascertained in several places, and the points united by exaggeration of the contour (Prop. 3), and by reversal of the windings, if the dip exceeds the slope of the surface feature.

The student should endeavour to realise what the outcrop of a bed will be across a hilly country, if its dip continue unaltered. A contour map must be used, with a point marked on it where a thin bed (or a line of division) is supposed to be dipping in a certain direction. A line drawn through this point, at right angles to the dip, represents the strike, and where it touches the surface the bed, or line, will be found. Therefore, those points where it crosses any contour line continuous with that of the supposed section, will be on its outcrop; and, joined by contours modified according to the dip's direction, will give the line required.

The exercise may be varied, in several ways, after a little practice; by assuming a change of dip at certain points; by adopting a given number of degrees of dip, and working out the position of outcrop in any definite locality; by inserting faults; and so on. But these had better be deferred until the rules, given in Part II., for working out the dip, have been considered.

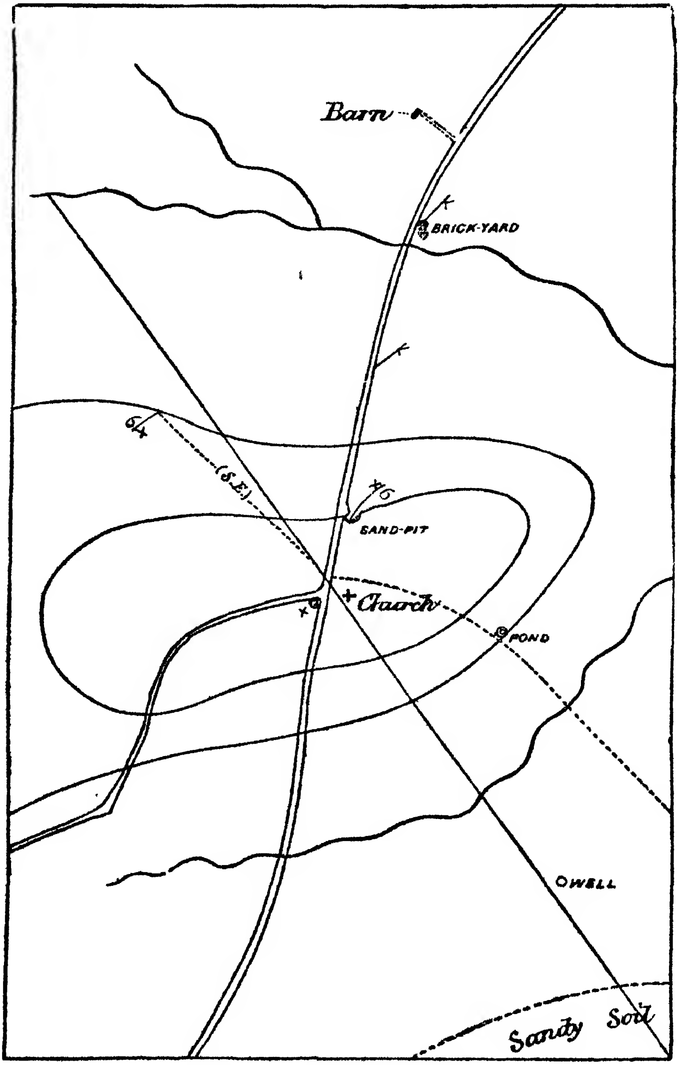

Fig. 5. First Slip (A[1]).

CHAPTER II.

SURVEYING *(continued)*.

Examples of Tracing Boundaries.

THE frequent reference to the map, during a geological survey, renders it desirable to have the plain copy, which is to be geologically coloured, cut up into slips of convenient size, say 6 by 4½ inches. These should be lettered and numbered at the back A^1, A^2, B^1, B^2, and so on; this plan provides for their being readily arranged and prevents confusion. The slips may be conveniently secured, by india-rubber bands, within the pages of a note-book or pocket map-case; but when six-inch maps are used they must be carried in cases slung from the shoulder. If the slips are all cut exactly to one size, they can afterwards be mounted on linen to fold in the manner described (p. 7).

Example 1.—Having procured, and cut up into slips, a map of the district to be surveyed, and provided ourselves with compass, clinometer, scale, hammer, and small bottle of dilute acid, we will proceed to the actual work before us. Let it be assumed that the slip numbered A^1, and represented by figure 5 (but of course without the geological lines, thereon), is to be the scene of our operations. We start, in imagination, from the church, which,

we are inclined to think from the white appearance of the soil, stands on the Chalk formation. This supposition is confirmed by an examination of the pond by the side of the road, for the excavation is three or four feet deep, and its sides exhibit clean-cut sections of that well-known rock. We note the fact by a symbol of some kind—a small x will do—marked on the map, at the pond, where the rock is exposed.

Proceeding along the road, down a rather steep hill, to the north, we find an old pit, now nearly overgrown, which turns out to have been formerly worked for sand. Is this a sand below the Chalk (which we may readily assume from its being at a lower level), or is it a bed of Drift on the flank of the hill? By picking about in places most free from talus, we discover that sand is not the only rock in the pit, for its upper part, on the south side, is in soft grey chalk. Clearing away the soil with our pick, we make a clean-cut vertical trench, and soon get at an actual junction of chalk and sand, the former overlying the latter; this is a useful discovery, and one that will not very frequently be made in practice. Sand-pits being dug for the sake of sand only, and chalk-pits for the chalk, it happens rarely, and then by accident, that pits and quarries are opened exactly on the line of junction. We indicate on the map the occurrence here of chalk over sand by the chalk symbol, x, above another for sand, for instance σ, with a short line between; thus $\frac{x}{\sigma}$. On referring to the map at any future time, we shall be able to tell, from the symbols, that certain rocks were seen at the points indicated, in actual section, and perhaps with a visible junction. Such records are the more valuable if

not inserted where any doubt exists without some mark, such as a line drawn around them, to distinguish them from symbols recording a fact about which there can be no question. The method of observing and noting this and other sections of the rocks, and the facts relating to them, thus and otherwise obtained, are hereafter described. (See Note *a*, chap. ii. in Part ii.)

The boundary of the Chalk of course passes through this pit, where the sand is seen coming out from beneath it; we accordingly draw a short line across the road here, which will presently be prolonged. Continuing our walk in the same northerly direction, we see nothing worthy of special remark except that the road, for some distance down the hill, runs through a sandy cutting, the slopes of which are clothed with ferns. Clay is visible in a newly-cut ditch about half-way down to the brook; this is a rock of another kind, and its occurrence may be indicated by another symbol, κ, at the spot where it is observed. Evidently we have come off the sand, but nothing as yet points out the line of boundary, and its discovery may for the moment be deferred.

We should expect to find the Upper Greensand beneath the Chalk, and below this again the Gault clay; we probably are now on the latter formation, but cannot be certain of this without further evidence. This is soon afforded by a brickyard on the other side of the brook, where the pit from which the brick-earth is taken furnishes ample justification for our coming to the conclusion that the clay is Gault, as anticipated. (See Note *b*, chap. ii. in part ii.) Northwards the clay forms a nearly level flat of rich pasture land, which extends apparently far beyond the margin of the map.

Retracing our steps, we observe, in the distance, a long heap of material recently thrown out from an excavation of some kind, a good way off on the west side of the road. To this we at once make our way, and it proves to be a trench, dug for a drain, at one part of which clean clay is turned out, and, a little higher up, light-coloured sand. The junction is not exactly visible anywhere, but it must be close by, and between the two places. We can commence our line here, but where are we? Away from the road, the brook, and everything else on the map; the church and a barn, both engraved on it, are, however, visible in the distance. Now the compass comes into requisition, and we take a bearing on the church; it reads S.E., and a pencil line is drawn accordingly. Taking a second bearing, this time on the barn, we get another line crossing the first at our exact position. Here then we insert our symbols $\frac{\upsilon}{\kappa}$, and begin to draw the line of division between the Gault and the Upper Greensand. Here also seems to be a slight alteration in the slope of the ground—the Gault makes almost a flat to the north, the sand rises more rapidly to the south, the change of feature due evidently to difference in hardness of the strata, or in their power of resisting denudation. The line must be drawn, as nearly as may be, where this change occurs, which seems also to very nearly follow the contour of the ground; if it should prove to coincide exactly with the contour, the strata at this point must be horizontal.

The line, thus drawn, winds somewhat, and crosses the road between the sand-pit and where clay was observed in the ditch. Beyond the road the change of feature becomes less distinct, but drawing the line as a

contour from the shape of the ground we find that it sweeps round to the right up the other valley, and just where it crosses a footpath there is a pond. By digging here with the spud, we can get no direct evidence, but, from the presence of the pond, we may fairly assume that thus far our line is correct. The pond would be near, and slightly above, the junction—dug through sand which yields the water, into clay, by which that water is upheld. Continuing the contour, it takes us across the road, which offers no evidence other than a slight change in inclination, the same as on the north where crossed by the boundary-line. It then goes on to the lane beyond, where, by picking in the banks we get sand in one place, clay in another just below it; between the two runs the line of boundary.

So far this is satisfactory, and we return to follow the boundary-line of the Chalk, the commencement of which was afforded by the junction seen in the sand-pit near the church. In passing up the lane we find out, by aid of the pick, and mark on the map, where it will be crossed by the Chalk boundary. Then from the sand-pit we draw a contour as before (getting here and there in the ditches a little evidence to check our work) round the point, across the footpath and the main road, through the spot marked in the lane, and on by the form of the ground. Here the line would seem to be turning back, as it were, upon itself, as if it would end where it began, in the sand-pit; it really does so, and the Chalk we have mapped is thus proved to be an 'outlier.'

We then walk over the ground on the south side of the brook, but find no open sections; in all the ditches clay is visible, except at the extreme south-east corner,

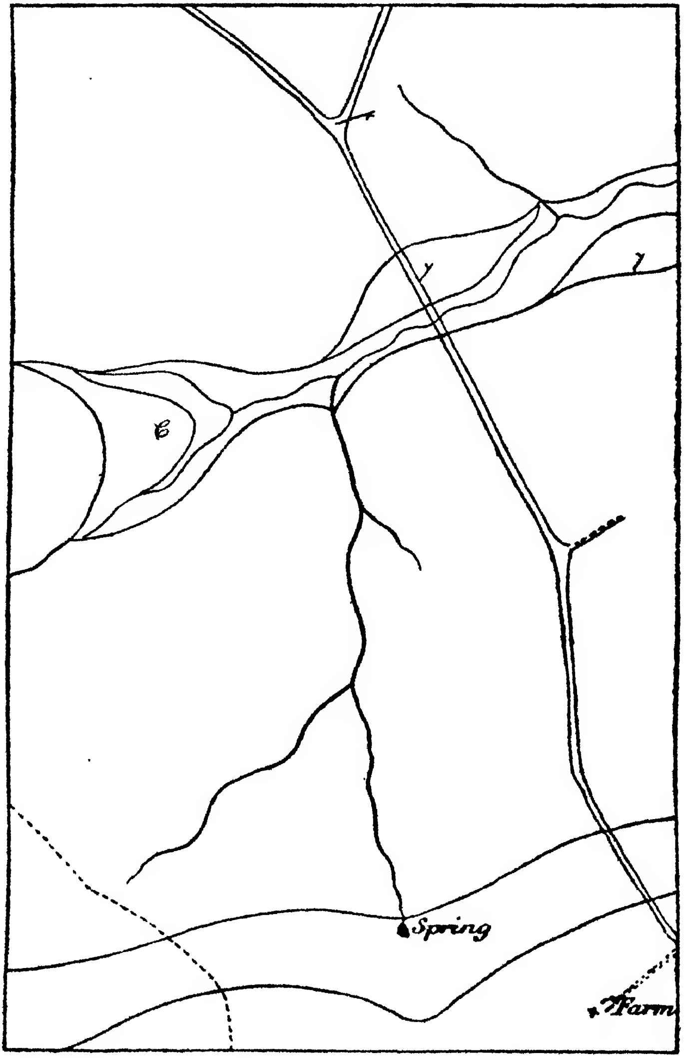

Fig. 6. Second Slip (A [2]).

where the soil is very sandy. A well has been sunk at a spot which we mark on the map, and it is stated to be 110 feet in depth, a fact which, with other particulars, we record in our note-book (See Note *c*, chap. ii. Part ii.).

The lines thus traced should be drawn afterwards, and whilst fresh in the memory, with Indian or other ink that will not run with wash of colour; the brick-yard, the sand-pit, and the section symbols being inked in at the same time. The pencil lines of boundary, bearing, etc., may then be erased, and the spaces between the lines tinted in any colours selected for the different formations. All notes and sketches should be revised and written in ink without delay; any errors will probably be seen at once and eliminated, and the maps and notes thus finished will be the more valuable because greater reliance can be placed upon their accuracy.

Example 2.—Let us now take in hand another slip, A^2, figure 6, which adjoins the east side of the one of which the surveying has just been completed. We will start at the south-east corner, where the ground is comparatively high and overlooks a broad flat to the north, which is traversed by a stream of fair size. The stream is formed by the union of the two small brooks in slip A^1 with another which runs in a northerly direction, evidently having its origin in a spring just below. Making a mental note of this fact—as the spring almost certainly rises at a point of change in the strata, probably at a junction of two formations—we commence our search for the rock immediately beneath us. This is soon dis-

covered to be Chalk, for it is exposed in a pit at the back of the farm (see Note *d*), and may be seen by spudding in the ditches at the roadside. It is, however, not as evident from the soil as in the first slip surveyed, owing probably to an accumulation of rain-wash on the surface at this point on the flank of the hill.

In passing northwards, along the high-road, and after losing the Chalk, we find that it passes between sandy banks, full of rabbit-runs and covered with furze. These suddenly cease, and a little farther on we see Gault clay; no good sections, but still the indications are sufficient to enable us to draw short lines where the road is most probably crossed by the two boundaries. Once on the flat, we observe nothing but clay until we approach the stream, which runs along a strip of flat marshy ground, that, to the eye, appears to be quite level. This is 'river alluvium,' and as such must be mapped; a very easy matter, which consists mainly in drawing a line where the slightly sloping surface of the Gault is lost in the level of the marsh. It is in fact a contour line; for this alluvial deposit is the result of repeated deposition from the flood waters of the river when it has occasionally overflowed its banks. This line is best drawn in walking along it, or nearly so, down one side of the stream and up the other; it is found to run a little way up the smaller streams and to die out just before we reach the west margin of the slip.

On the same side of the road a bed of yellow loam is exposed in a small brick-yard (see Note *e*), it thickens towards the valley and thins out westward. It lies, in fact, on the flank of the rising ground, where the two small streams converge, and it runs down to,

and probably under, the alluvium. As the upper edge of this loam gradually thins out against the Gault hill, its boundary-line is, of course, very indefinite. There are some beds of gravel, on the east side of the road, which make a much more distinct boundary, the difference being greater between Gault and gravel, than between Gault and loam. The gravel is seen in section in two or three pits (see Note *f*), from which the stones have been dug for road-mending, and from which, we are informed, some large bones (? extinct mammalia) have been occasionally taken by the workmen.

A clean section of the Gault is seen in a hole by the branch-roads on the north side of the river, but no other actual evidence, although we walk all over the flat at the north-west corner and down the west side, until we strike the footpath, when Gault is again visible. Following the footpath, we note that the soil gets more sandy, and, at the rising ground, we come upon sand, note approximately the junction, and a little higher up find by digging that the sand passes in under the Chalk. It is now simply a matter of continuing to draw these two boundaries; the lower one passes through the spring seen from the high ground, which throws out water at the junction of the Gault and Greensand. By this the general accuracy of the work is proved, and both boundaries cross the road where we had drawn the short provisional lines soon after starting.

Example 3.—Having heard that there is a Chalk-pit by the side of the road that crosses the third slip, B^1, figure 7, we will commence operations there or there-

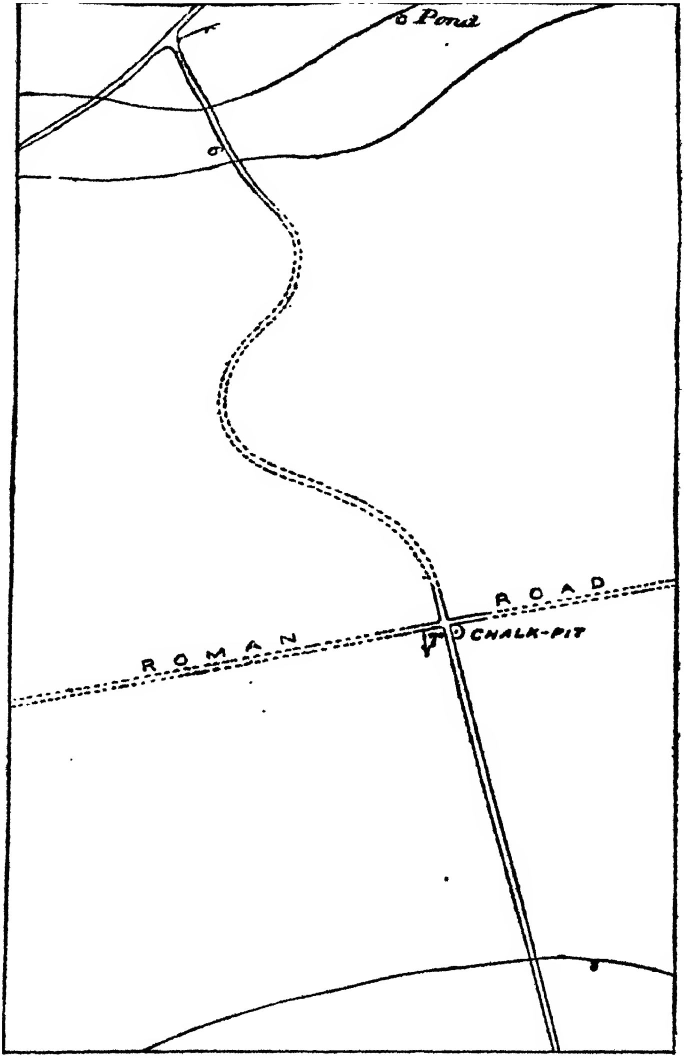

Fig. 7. Third Slip (B [1]).

abouts. On the way to the pit, and near the southern margin of the map, clean grey sand has been thrown out from a hole newly-dug for a gate-post; this is very different from the sand, full of green grains, seen in the first and second slips surveyed, and we conclude, from the level and general run of the country, that the sand can hardly pass beneath the Chalk. However, no other good section is obtainable, and there seems no chance of getting at the junction, for the soil is deep and there are no ditches worthy of the name. We can simply dot in a line where the sandy soil appears to end, and so for the present leave it and get on to the Chalk-pit.

This is a fine excavation on the very highest point in the map, and to the north commands a view down and beyond the escarpment, which at once indicates that the mapping of this slip will give but little trouble—Chalk, bare Chalk, in rounded hills and hollows, everywhere is visible. Having made our notes in the pit (see Note *g*), we descend the road which winds down the steep slope, and has been cut through the higher ridges, frequently exposing the Chalk—in its upper part with layers of flint, in its lower portion without any flints at all. Further on is an exposure of sand, and still further, where the roads meet, a small pit in clay—the same kind of thing exactly that was met with in our first and second slips—and on turning up the road to the left we make out, by digging, a junction of the beds. These are then easily traced to the margin of the map, by feature in the usual way, the lower line running just by a pond that is supplied with water from the junction of the sand and clay.

All the intervening ground is walked over, to make

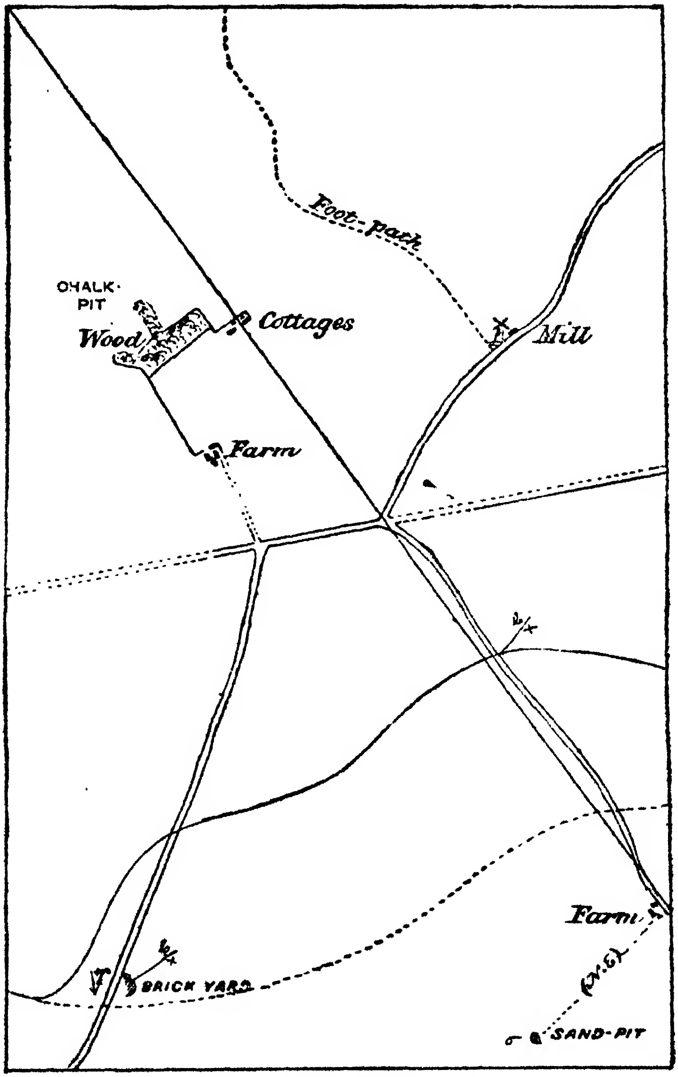

Fig. 8. Fourth Slip (B [2]).

sure that no open sections have escaped notice ; and a few heights are taken, from which the thickness of the formations may afterwards be calculated.

Example 4.—In making another expedition to survey the fourth slip, B², figure 8, we enter upon its area, let us suppose, near the top of the Chalk escarpment, which is completely overlooked from the road. We pass on by the windmill, not troubling to search for sections, as Chalk everywhere abounds, turn to the left at the branch roads, and presently come to a road-cutting. The slopes are covered with vegetation in marked contrast to the general aspect of the Chalk area, but we dig in several places and find loam, mottled in yellow, red, and brown colours, unusually bright for earthy materials. In the third slip we found grey sand, apparently resting on the Chalk—this variegated loam is something very different, but occupying apparently a similar position. We dig a trench down the side of the cutting to ascertain if the grey sand be here beneath the loam, but it is not, and we come instead upon a bed of dark brown clay enclosing green-coated flint pebbles, and below this the Chalk itself. We make our notes of these facts (see Note *h*), find our exact position on the road by a bearing on the windmill, and draw a line across it at the boundary. Nothing more, worthy of note, occurs until we come to a small pit near the corner of the map, dug into clean grey sand similar to that in the third slip (see Note *i*). This is also put down on the map by aid of a bearing on, and by pacing the distance from, the farmhouse, as no other object is visible on which to take a second line of bearing.

On the east side of the other road in the slip is a brick-yard, which gives a very useful section (see Note *k*). Here the junction of the Chalk with the overlying mottled loam is visible, the latter including the brown clay with green-coated pebbles. We ascertain that sand occurs just to the south, and we conclude that the sand must rest, at this point, on the loam, which thins out to the south and west beneath it; if so, the sand in the third slip lies, as was supposed, directly on the Chalk (see Geological Section, fig. 27, p. 123). Getting occasional hints from the drains and ditches, and boring, here and there, through the soil on either side of the probable line of boundary, we are enabled to draw our lines, which when finished support this interpretation.

Proceeding in a northerly direction, about mid-way between the two roads, we pass by the farm on the higher part of the hill, and, at the west corner of the wood, find a pit in hard, finely-bedded chalk, grey in colour and very fossiliferous. Notes are taken in the usual manner (see Note *l*), and the survey of the slip is completed.

The four slips supposed to have been surveyed, although forming parts of one map, have been, for the sake of perspicuity, hitherto treated as if relating to distinct areas; on placing them together, in the position indicated by their distinguishing letters and numbers, they will be found to correspond, on a larger scale, with the coloured map (Frontispiece). The slips may be considered as a working, or field-copy, cut up for con-

venience of carriage; the map as coloured and completed, for reference or publication.

This geological map, drawn and coloured from data obtained in the manner described, shows the outcrop of four formations; a section, perhaps several hundred feet in depth, showing their thickness and their relation to each other, can be drawn from it, and from notes taken in the several pits during the progress of the survey. The mode of observing the facts for drawing this kind of section, and the various ways of ascertaining, for that purpose, the surface-levels, or heights, along the section-line, are described in Part II. The methods of determining the lithological and palæontological characters of the rocks are given in Parts III. and IV. The more complicated process of mapping the older and disturbed or faulted rocks (of which an example appears at p. 73), is much facilitated by an acquaintance with the rules and methods given as memoranda in the following chapter.

CHAPTER III.

SURVEYING (*continued*).

Traversing—Symbols—Memoranda—Drift Deposits.

Traversing.—In surveying a district of which it is necessary, or desirable, to map the outcrop of the strata very accurately, the ground must be gone over much more closely than is indicated by the simple examples selected for illustration of the method of geological surveying. It is then well to follow all the lines of ditch and fence by which the area is intersected, as these, although somewhat irregular, serve to guide one in traversing all the ground without going twice over any portion. Such lines are occasionally too far apart for the purpose, when they must be left, and the intervening spaces walked over, in search of sections and other evidence.

The opposite diagram (figure 9) shows two very good methods of traversing ground—one on each side of the main road—the dotted line, starting from the church, traces the path along which the walk is taken. It will be seen that these dotted lines cover the area at a width of one field apart; if a pond be seen, or if the chance of any other section should offer, it is worth while to make a divergence. By walking over the ground in

this way, all the details of the strata, however numerous they may be, are collected at once, and a portion, first of one line, then of another, is drawn, as the boundaries are crossed and recrossed. But sometimes it is found more convenient to commence and follow out one line; this is best done by walking along a ditch or fence until the line is passed, then along the bottom of the field to the next fence, up this until it is again crossed, and so on.

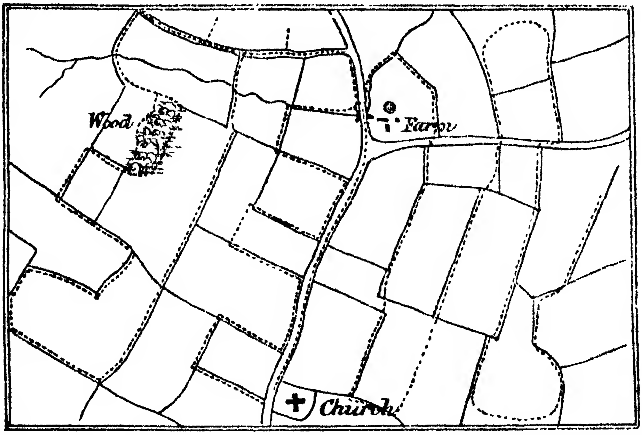

Fig. 9. Showing, by dotted lines, Two Methods of Traversing Ground: one on each side of the road.

All railway cuttings and excavations for new buildings should be visited and examined, all wells, whether new or old, should be especially scrutinised, and all particulars obtained regarding the strata through which they pass, the origin of their supply, and the water-level. Farm labourers and workmen can generally tell where pits may be seen, and in a difficult country may give some ideas as to the nature of the strata beneath, which, however, cannot (except in rare instances) be

taken as reliable information. Setting aside any chance of mistake through the use of provincial terms, the absence of knowledge they exhibit on this point is remarkable. On the other hand, the details given, in most cases freely, by landowners and farmers, are of considerable value, because, as a rule, they are worthy of dependence.

Signs and Symbols.—Three sets of symbols are given below, in Table I., and may be found useful for marking the occurrence of certain rocks where seen in section. Any other letters, figures, or devices, would answer the purpose perhaps equally well, but the Greek letters are recommended for simplicity and convenience; the tail possessed by each letter is serviceable, when prolonged, in marking the exact spot at which a section is visible.

TABLE I.

Limestone	λ	*l*	//
Dolomite. Diorite	δ	*d*	/:/
Chalk	χ	*ch*	||
Chalk, with Flints	⁎	*cf*	|:|
Sandstone. Sand. Serpentine	σ	*s*	.
Coal. Clay. Shale. Slate. Schist	κ	*cl*	=
Clay-Ironstone	κι	*i*	o
Felstone. Phonolite	φ	*F.Ph.*	·|·
Boulder clay. Basalt	β	*B*	÷
Brick-earth. Loam	ς	*b*	⊤
Gravel. Conglomerate. Grit. Granite. Gypsum	γ	*g*	∴
Peat. Porphyrite. Phosphate	μ	*p*	≈
Alluvium Marsh	*a*	*A*	ϒ

Two or more symbols may be arranged to show, at a glance, the relative position in which the beds are seen in section, with a line or lines between them indicating the inclination (if any) of the divisional planes of stratification, or the existence of a fault. Thus a section of gravel, over limestone faulted against sand, would be shown thus, , and a bed of clay, resting on sandstone and dipping in the same direction, in this manner, .

Table II. gives the signs engraved on the maps of the Government Geological Survey, used to indicate the occurrence, at the points where they are shown, of certain phenomena, or of natural or artificial sections, that have come under actual observation or have been obtained through authentic information; Table III., the distinguishing letters of each formation.

TABLE II.

Signs connected with Stratification.

+	Horizontal
+	Vertical (longest line on the strike)
×	Undulating
	Contorted
	Highly inclined } With general dip in the direction of the arrow.
	Undulating } With general dip in the direction of the arrow.
	Contorted } With general dip in the direction of the arrow.
	Anticlinical axis
✳	Synclinical axis
	Dip from observation (with No. of degrees, thus 5°)
	Dip from information
	Cleavage
	Limestone quarries
S. Q.	Slate quarries

Interrupted Lines=A doubtful or drift-covered boundary.

White Lines=Faults at the surface.

Yellow Lines=Faults underground.

Thick Black Lines=Coal crops. When doubtful, lines interrupted.

○ Bore hole
⊖ Mine shaft
⇑DH Day hole (entrance to adit)
═══ Colliery levels

SIGNS CONNECTED WITH THE GLACIAL DRIFT.

Roches moutonnées		
" " striated Flat surface striated	}	Direction of Ice-flow not apparent.
Roches moutonnées striated Flat surface striated	}	Showing direction of Ice-flow.

SIGNS INDICATING THE ORES OF THE METALS.

☉ Gold	☽ Silver
♀ Copper	♃ Tin
♄ Lead	⋇ Manganese
♂ Iron	♃ Zinc

Gold lines=Mineral Veins.

Gold dots=Stream Tin.

Gold rings=Pipe Veins.

TABLE III.

Tertiary.

	i 10.	Hempstead Beds (Marls and Clays).	Fluvio Marine Series.		Upper.	Eocene.
	i 9.	Bembridge Beds (Marl, Limestones).	Fluvio Marine Series.		Upper.	Eocene.
	i 8.	Osborne or St. Helen's Beds, Headon Beds (Marl, Limestones, and Sandstones).	Fluvio Marine Series.		Middle.	Eocene.
	i 7.	Upper Bagshot Sands.		Bagshot Beds.	Middle.	Eocene.
	i 6.	Barton Clay.	Middle Bagshot Beds.	Bagshot Beds.	Middle.	Eocene.
	i 5.	Bracklesham Beds (Clays and Sands).	Middle Bagshot Beds.	Bagshot Beds.	Middle.	Eocene.
	i 4.	Lower Bagshot Beds (Clays and Sands).		Bagshot Beds.	Middle.	Eocene.
	i 3.	London Clay (and Bognor Beds).	Upper.	London Tertiaries.	Lower.	Eocene.
South of England.	i 2′.	Oldhaven Beds (Sand and Pebble Beds).	'Plastic Clay.' Lower.	London Tertiaries.	Lower.	Eocene.
South of England.	i 2.	Woolwich and Reading Beds (Clays, Sands, and Pebbles).	'Plastic Clay.' Lower.	London Tertiaries.	Lower.	Eocene.
South of England.	i 1.	Thanet Beds (Sand, Loam, and Sandy Marl).	'Plastic Clay.' Lower.	London Tertiaries.	Lower.	Eocene.

Secondary or Mesozoic.

h 5.	Upper Chalk (mostly with Flints).	Chalk.	Upper.	Cretaceous.	Upper Mesozoic.
	Lower Chalk (mostly without Flints).	Chalk.	Upper.	Cretaceous.	Upper Mesozoic.
	Chalk Marl (and Chloritic Marl).	Chalk.	Upper.	Cretaceous.	Upper Mesozoic.
h 4.	Upper Greensand (Malm Rock, Firestone, etc.).		Upper.	Cretaceous.	Upper Mesozoic.
h 3.	Gault (Clay).		Upper.	Cretaceous.	Upper Mesozoic.

TABLE III. (*continued*).

Secondary or Mesozoic (*continued*).

Locality	Symbol	Sub-symbol	District	Beds	Group	Sub-series	Series	Division	System
I. of Wight and rest of England.	h 2.	$h^{2''''}$	Surrey, Kent, Sussex, and part of Hants.	Folkestone Beds (Sand).	*Lower Greensand.*		Upper Neocomian.	*Lower.*	Upper Mesozoic (*continued*). Cretaceous (*continued*).
		$h^{2'''}$		Sandgate Beds (with Fuller's earth).					
		$h^{2''}$		Hythe Beds (with Kentish Rag and Bargate Stone).					
		$h^{2'}$		Atherfield Clay					
Dorset, Wilts, and I. of Wight.	h 1.	h^{1}, h'''	Surrey, Kent and Sussex.	Weald Clay (with Horsham Stone).	*Clay.*	*Weald*	Wealden Series.		
				Up. Tunbridge Wells Sand		*Hastings Beds.*			
				Cuckfield Clay					
				Grinstead Clay, and Lower Tunbridge Wells Sand					
		h''		Wadhurst Clay (with Iron-ore).					
		h'		Ashdown Sand.					
		h		Fairlight Clays (Ashburnham Beds of the Hastings Cliffs).					
Wilts, Bucks, and Sussex.	g 14.	$g^{14''}$	Dorset.	Upper	Purbeck Beds.	Purbeck Beds.	Purbeck Series.	*Upper.*	Oolitic. Jurassic. Lower Mesozoic.
		$g^{14'}$		Middle					
		g^{14}		Lower					
	g 13.			Portland Stone and Portland Sand.		Portland Beds.	Portland Oolite.		
	g 12.			Kimeridge Clay.					
	g 11.			Upper Calcareous Grit.		Coral Rag.	Oxford Oolite.	*Middle.*	
				Coral Rag (with Iron-ore).					
				Lower Calcareous Grit.					
	g 10.			Oxford Clay (with Kellaway's Rock at the base).		Oxford Clay.			

TABLE III. (*continued*).

g 9.	Cornbrash	Great Oolite.	*Lower.*	OOLITIC.	JURASSIC.	LOWER MESOZOIC (*continued*).
g 8.	Forest Marble and Bradford Clay.					
g 7.	Great or Bath Oolite (Clays and Limestones) with Stonesfield Slates near the base.					
g 7′.	Upper Estuarine Series.					
g 6.	Fuller's Earth.	Inferior Oolite.				
g 5.	Inferior Oolite Limestones.					
g 5′.	Northampton Sand, including Lower Estuarine Series.					
g 4.	Sands.	Lias.	*Upper.*	LIASSIC.		
g 3.	Upper Lias (Clay).					
g 2.	Middle Lias or Marlstone (Rock bed, Sands, &c.).		*Middle.*			
g 1.	Lower Lias (Limestones and Clay).		*Lower.*			
f g.	'White Lias' / Penarth Beds — Rhætic Beds.					
f 6.	Upper Marl, with Sandstones.	Keuper.		TRIASSIC, OR NEW RED SANDSTONE.		
	Red Marl, with Gypsum and Rock Salt.					
f 5.	Lower Sandstone and Marl (Waterstones).					
f 4.	Dolomitic Conglomerate. Somerset, Gloucester and S. Wales.					
f 3.	Upper Red and Mottled Sandstones.	Bunter.				
f. 2.	Pebble Beds, Calcareous Conglomerate and Breccia. — Middle Bunter.					
f. 1.	Lower Red and Mottled Sandstones.					

TABLE III. (*continued*).

Primary or Palæozoic.

e 5. Upper Marls. e 4. Upper Limestones. e 3. Middle Marl and Sandstones. e 2. Red Marl, with bands of Magnesian. Limestone (Lancashire and Western England). Lower Limestones. Thin Sandstones and Quicksand.	Magnesian Limestone Series, ('Zechstein.')	Permian.	Upper Palæozoic.
e 1. Sandstones. Conglomerates and Marl (with calcareous bands). Angular Breccia and Calcareous Conglomerates.	Lower Permian Rocks, ('Rothliegende')		
d 5. Coal Measures and Sandstones.	Coal Measures.	Carboniferous.	
d 4. Millstone Grits and Shales.	Millstone Grit.		
d 3. Yoredale Grits, Sandstones and Shales. d 2. Carboniferous Limestones, Coals, Shales and Sandstones.	Carboniferous Limestone.		
d 1. Limestones and Sandstones (in Scotland with Cornstones).			
c 3. Upper Devonian (Sandstones, Conglomerates and Limestones). c 2. Middle Devonian (Limestones). c 1. Lower Devonian (Sandstones, Conglomerates and Limestones).		Old Red Sandstone and Devonian.	Lower Palæozoic.

TABLE III. (*continued*).

Primary or Palæozoic (*continued*).

b 7‴.	Tilestones.	Ludlow Beds.	*Upper.*	Silurian.	Lower Palæozoic (*continued*).
b 7″.	Upper Ludlow Beds.				
b 7′.	Aymestry Limestone.				
b 7.	Lower Ludlow Beds.				
	Bannisdale Beds.				
b 6‴.	Wenlock Limestones.	Wenlock Beds.			
b 6″.	Wenlock Shales (with Sandstones and flags).				
b 6′.	Woolhope Limestones and Shales.				
b 6.	Denbighshire Shales, Slates and Flags.				
	Conistone Grits and Flags.				
	Tarranon Shale (or pale slates).				
b 5.	Upper Llandovery Rocks, (May Hill Sandstone).	Llandovery Beds.			
b 4.	Lower Llandovery Rocks, (Conglomerates, Sandstones and Shales).				
b 3.	Coniston Limestone and Shale.	Caradoc or Bala Beds.	*Lower.*		
	Caradoc or Bala Limestones (often shelly), with Bala Limestone, Shale and Slate.				
b 2.	Skiddaw Slates.	Llandeilo Beds.			
	Flags, Limestone and Conglomerates, with Graptolite Shale and Slates.				
	Slates and Sandstone.	Tremadoc Beds.			
b 1.	Siliceous Grits, Flags and Slates.	Lingula Beds.			

TABLE III. (*continued*).

PRIMARY OR PALÆOZOIC (*continued*).

a 1.	Harlech, Llanberis, St. David and Longmynd Grits and Conglomerates, with Purple and Green Slates.	CAMBRIAN.	LOWER PALÆOZOIC (*continued*).
A.	Laurentian (Fundamental Gneiss) of the N.W. of Scotland. (Not yet mapped.)		

G^n.	Diorite (Greenstone).	
B.	Dolerite (Basalt).	
S.	Syenite.	
F†.	Felstone.	
P†.	Porphyry.	
G.	Granite	
	Granitic.	Dykes.
M.	Micaceous (or Minette).	Dykes.
E.	Elvans of Cornwall (mostly Granitic and Felsitic).	Dykes.
F.	Felsitic	Dykes.
H.	Hornblende Slate.	
Hy.	Hypersthene Rock.	
D.	Diallage Rock.	

δ 4.	Altered	Millstone Grit.
κ.	"	Devonian.
β 5 to 7.	"	Upper Silurian.
β 1 to 4.	"	Lower Silurian.
a 1.	"	Cambrian Grits and Conglomerates.
a 1.	"	" Slates and Limestone.

Σ. Serpentine.

Memoranda useful in Geological Surveying.—It is not often that the evidence for drawing geological lines will be found as clear as it has advisedly been assumed to be in the district, comparatively free from drift, covered by the four slips surveyed. The relations of Chalk, Greensand, and Gault are usually clear, present several marked characteristics, and, in England, are not much interrupted or disturbed. Frequently, in surveying less distinctive rocks, many miles may be walked without any data being observed which will warrant the final drawing of a boundary-line; it must then be carried provisionally through the most likely points, to await further evidence. Should this not be forthcoming, the line may be dotted in ink, as being uncertain, but one slip, or one area, will sometimes elucidate what is obscure in another. As a simple instance of this may be noted the Upper Greensand, mapped in the second and third slips, which proves that the sandy soil at the south-east corner of the first slip is due to that formation, although no sections were there observed.

Where there is but little or no change of feature, the line being traced should be kept well up above where it would at first seem to run—for, not only is the *débris* of the upper rock constantly falling upon the outcrop of the one below, but the soil also which properly belongs to it is continually being washed down to a lower level. This, for some distance down, gives a deceptive indication of the presence of the upper rock where the lower only would be found on making an excavation. The eye, however, by practice, gets accustomed to look and to make allowance for this condition of things, and will assign almost intuitively its proper place to the line of division.

It frequently happens that lines have to be traced through large parks, where the soil is completely covered with grass, and no ditches are to be seen, through thick or large woods, across barren moors, and under broad spreads of alluvial marsh-land, where no evidence whatever can be obtained. The difficulty in tracing the lines in these cases may be considerably lessened, by first mapping for a good distance around such obscure areas. From the data thus collected, and the knowledge gained of the nature and lie of the beds, the lines may be run by feature alone with every chance of an approach to accuracy.

Strata, when surveyed over large areas, are almost sure to be found to change in the amount or direction of their dip, and to undulate so as to form synclines and anticlines of more or less importance. By even slight undulations, lower beds may be brought up and exposed by denudation, although entirely surrounded at the surface by the bed above them, and thus form 'inliers.' This term is useful, but not strictly accurate, as opposed to 'outliers,' which are portions of rocks detached, or outlying, from the main mass. Inliers are exposed portions of, but are not separated from, the rock thus brought up by denudation.

Beds, and even formations, are sometimes transgressive—that is, the upper extends in some direction beyond the lower (which thins out beneath it), although the two may have virtually the same inclination. 'Overlaps' become apparent, even when not seen in section, through the lines of boundary, of the two beds in question, gradually approaching, and the outer (or lower one being lost beneath the other. Where 'un-

conformity' exists between two beds or formations, that is where the upper rests upon the denuded edges of the lower, with a great or small difference in inclination, the lines of boundary will (in most cases) approach each other with greater abruptness, often at a considerable angle.

These phenomena of overlap and unconformity, as well as of fractures in the beds, called 'faults,' will perhaps not be evident until a considerable area has been surveyed, except, of course, when seen in actual section. When any unusual difficulty arises in surveying a district, it is probably owing to something of this kind; every line must then be followed as far as possible, and every detail noticed with the greater accuracy. By going carefully over a good-sized area in the difficult country, surveying and recording the observed facts without reference to the possible fault or unconformity, lines will be laid down which of themselves will go a long way towards affording the correct explanation.

When walking over and geologically surveying an area, it may seem almost impossible to, as it were, convert oneself into a surveying machine—to simply dig out certain physical facts—to put down on paper what one actually sees or discovers, and for the time do nothing more—yet, within due limits, this is the best plan that could be adopted. The occupation undoubtedly affords much ground for speculation, as to the extent of this rock, and the thickness of that, the relation of the one to the other, the age and origin of each, and the amount and kind of denudation to which it has been subjected. This is pleasant amusement enough, and in

one sense profitable also, but a geologist thus speculating before he has obtained sufficient data on which to base his ideas is really theorising, and may very readily arrive at wrong conclusions. Unless he tries, however, to realise the internal structure of the country, the surface of which he is surveying, he may miss the observation of facts in favour of, or adverse to, any particular theory of geological interest. He should not commit himself hastily to the support of any hypothesis, but carefully think over possibilities, ever holding himself ready to abandon any views proved to be untenable. It is astonishing to find how strongly the facts afterwards ascertained may seem to support, when they in reality condemn, a theory thus preconceived. But the machine-like method of procedure should be, as far as possible, followed, until a considerable area has been accurately mapped, and all available data obtained and correlated; then a theory, or it may be a generalisation, can be based thereon, with a reasonable faith in its soundness and truth.

When such an area has been surveyed, all the evidence upon which the work is based should be re-considered, with the view of making, at once, any necessary corrections; it being impossible, in the earlier part of the survey, to grasp all the details of geological structure. There may be regions, destitute of soil and superficial accumulations, where the actual strata, and the lines of division between them, are visible at the surface. Such conditions are, however, abnormal, and the work has really to be done from evidence obtained at isolated points, connected on mathematical principles, and correlated by a process of induction. Still the geologist,

when making his survey, must of necessity form, and keep in his mind's eye, an idea of the country as it would appear with its soils and drift-deposits removed. And when his map is completed, he may carry the process still further, and in his mind decide what are the actual conditions of the rocky formations even below those he has delineated. In certain cases, as of overlap and unconformity, the lines of a lower have to be carried beneath an upper formation. This is done by accurately surveying those lines, as far as they continue at the surface, and then by connecting them, where hidden by drift or any other overlying formation. These hidden lines are drawn, as nearly as possible, as they would appear, were the overlying beds removed, and to do this, their own dip, and the probable thickness of the upper rocks, must receive careful consideration.

Drift Deposits.—There are certain deposits of gravel and clay, to which the methods of mapping hitherto described are scarcely applicable, without additional suggestions. The student will have made himself acquainted, theoretically, with the phenomena of the 'Glacial Period,' but the relics thereof, which he will come across in his field expeditions, are sometimes very puzzling in their nature and relations. Still the 'Drifts,' as they, in common with more recent deposits, are called, may be classified, and no geological map can be considered complete from which they have been omitted. The products of the climatic and physical conditions that prevailed in the Glacial epoch, are clays, gravels, and sands, all of peculiar character, and very irregular in their distribution and mode of occurrence. The clays formed during this period, and due to the

action of ice in some form, terrestrial or marine, may be, when seen in section, readily distinguished. They are unstratified, sometimes contorted, and, almost without exception, they enclose fragments, or boulders, of older rocks; from this circumstance is derived their name of Boulder Clay. The deposits vary in colour, according to that of the rocks from which they were derived; and it is difficult sometimes to separate them from the beds on which they lie, owing to the similarity in their colour and composition. The included fragments are all, more or less, worn by attrition, and are frequently smoothed or polished on some of their sides, and are marked with striæ in sets, crossing each other at various angles. The striæ are sometimes so fine as to be scarcely perceptible, sometimes so broad and deep as to form veritable grooves. The smoothing, scratching, and grooving, are the result of ice action, and are known by the general term 'ice-markings.' These markings are found not only on the boulders, but on the surface also of the rocks (whether now covered or not by drift), which have been subjected to glacial erosion. Such phenomena should always be looked for, and noted, the character and direction of the ice-markings receiving careful attention.

The glacial gravels are distinguished also by a general but not constant absence of stratification, by frequent contortions, and by their rapidly-varying character; here coarse and angular gravel, there fine sand, or even laminated brick-earth. Except in a few localities, and within limited areas, these beds are unfossiliferous, therefore evidence as to the age or origin of any particular deposits must be sought in their stratigraphical

relations. And for this purpose the frequently scanty items of evidence to be obtained from sections, and the inferences from feature, must generally be depended on for determining the order of their super-position. Where no sections showing junctions are met with, the form of the ground will afford some hints as to which of two beds is the upper, and which the lower, for a gravel overlying clay will not make quite the same kind of feature as it does when passing beneath. It will generally be found that a hill with rounded outline, consists of clay; if its lower part be gravel, or sand, comparatively steep, such gravel or sand may reasonably be supposed to pass under the clay—for the lower part of a bed of gravel or sand, protected above by a more tenacious bed of clay, is cut back at a rate disproportionate to that of its upper part, and a more or less abrupt rise is the result. If, on the contrary, it forms a flat or sloping plain, it probably rests upon the clay, thinning out against the flank of the hill, and getting thicker towards the valley. Gravels frequently make level flats, and sometimes long ridges, cut off, as it were, from the land at similar heights around them; in the latter case they occupy old channels, a position which has preserved them when the ground on either side has been removed by denudation.

These glacial deposits may, and do, occur either singly or together, sometimes one may be absent, sometimes another; but the peculiarity of them all is, not being confined to any definite level, having indeed neither true dip nor horizontality. They spread indiscriminately over an old denuded surface, high and low ground alike, capping the hills and filling the valleys, so that over large areas the underlying older formations are com-

pletely hidden—and this perhaps by a sheet of material which, compared with the older formations, is comparatively thin and unimportant. A drift clay may be found in one place on the top of a hill, and neither on its flank, nor at its foot, but a few hundred yards away, it may perhaps be discovered trailing down the slope, and even crossing the valley, with none whatever on the higher ground. This must necessarily be the case, for the drifts repose on an old irregular surface, and those portions which occupied the ancient hollows and channels remain now as portions of a level surface, or even as elevated ridges.

The older river-gravels occur in somewhat similar positions, having been preserved in the same manner, as ridges or terraces, above the level of the present bottom of the valleys. These may, however, be distinguished from the glacial gravels, by their being more evenly stratified, by the stones being more uniform in size in any given bed, and more angular, and by their frequently enclosing patches of loam in which may be found recent land and freshwater shells.

These old valley gravels are now reduced to mere remnants in comparison with their former extension, but from their consistency and frequent linear arrangement of the patches, are much more easily mapped than are the glacial drifts. The latest deposits of all, as brick-earth, gravel, and sand, occur at about the same level as the rivers, being frequently found first on one side, then on the other, of existing streams; the present channel running along one edge of the deposits, then cutting across to follow for a distance the other side, as shown in the second slip surveyed, and by the

stippled area in the frontispiece. The lines of alluvium or marsh-land are, as we have seen, readily drawn, and it is a good plan in making a geological survey for this deposit to be the first mapped. One thus gets the best chance of seeing sections in the lowest beds, and obtains also an idea of the physical geography, or at all events of the valley-system, of the district. The recent valley-beds will be found in greatest force where older gravels occur, on the higher grounds in the same locality, and from which their material is chiefly derived. Where a stream has widened out, or where two streams have joined, and where the waters will have slackened in consequence, loam or brick-earth will generally be found; a little lower down, where the united waters have run more rapidly, gravel will have been deposited.

The boundary lines of drift must be closely followed, if an accurate map of the beds be desired—contour is of but little use, except as a guide to the eye, in drawing lines between the points through which they have been found to run, and these points should be separated by no great distance.

It is well to remember that in 'drifts,' the lower, as regards level, is not necessarily the older, of two or more deposits; take, for instance, the gravels occurring in a large drainage area. In past time, the river has formed a large sheet of gravel, through which, as denudation went on, its course was cut with a lowering of its level, perhaps 20 feet. It deposited more gravel, which was in turn cut through, and the river's course was again lowered, it may be other 20 feet. In such a case the gravel at the higher level is the older, and the various deposits now form terraces at heights 20 feet apart,

marking as many stages in the formation of the valley. Such are the higher, lower, and intermediate terraces of gravel found in the valley of the Thames, and other rivers—the higher, and older, enclosing the remains of extinct animals and of palæolithic man, each succeeding lower terrace more nearly approaching to the existing state of things, and the last deposits having been formed within quite recent periods.

The occurrence of glacial- and river-drifts, which now form plateaux and ridges, but which (at all events the gravels) must have been originally deposited in hollows and channels, has been several times referred to, and must come under frequent observation. The same phenomenon is noticeable also in the older rocks, especially where they form tongues and outliers, and it arises from the fact that in all rocks, hard or soft, old or recent, an anticlinal line is the most readily denuded. Partly, it may be, from the bend having, on the upper side, slightly opened out the particles by tension, thus, in some cases, producing fractures, and in others weakening the power of resistance. Partly, or it may be entirely, to the resulting inward and downward dip of the beds on each side of an anticline, which would make them relatively stronger, than the intervening flat part, to resist the attacks of erosion. Another and not unimportant reason may be, that a considerable portion of the rain falling thereon percolates down into the rocks having such an inclination and is thrown out elsewhere, while directly along the axis of elevation, it all flows over the rock and removes a proportionately larger share of material.

CHAPTER IV.

SURVEYING (*continued*).

Survey of Older Rocks—Examples of Tracing Boundaries and Faults—Eruptive Rocks—Veins.

Survey of Older Rocks.—In mapping the older rocks, it is a good plan first to make oneself well acquainted with the physical geography of the district to be surveyed; to find out the watershed of the area, the system of its valleys, the highest points of its hills, and the amount of their elevation. These points will afford indications of how the rocks, if not eruptive, will be found to run; for, as stated in page 24, beds almost invariably dip towards higher ground, to the form of which their inclination has indeed greatly contributed; therefore the contour of a hill approximately indicates the local strike, or rather outcrop, of the beds of which it is composed. Where there are continuous escarpments, long ridges, and sweeping valleys, we expect to find a tolerable consistency in the inclination of the strata; in a rugged, broken surface we see indications of sudden changes of dip, both in amount and direction, of faults, fractures, and contortions.

Contour maps of a new area are especially valuable for this purpose, and form physical maps, almost equal

to relief models, if the spaces between the contour-lines be shaded in graduated tints. Without actual inspection of a district, maps thus prepared afford a knowledge of its shape, and the probable lie of its rocks, which will be found of the greatest assistance.

The next step would be to visit all the quarries, lime-kilns, brick-yards, or coal-mines, the existence of which we have been able to ascertain, and in all of them obtain, by inspection and inquiry, some useful information. By these means we get, not only a good general idea of what the rocks of the district are, but also a knowledge of the exact nature of some, of the formations to which they belong, and probably of their local thickness, dip, and other characteristics.

Where sections are plentiful, the thickness and dip of all the various beds of a district may of course be readily ascertained. If, in addition to this, the relative surface heights be known, from contours or otherwise, several points of outcrop can be worked out, and connected by lines, modified in accordance with one or other of the General Propositions (pp. 23—25). It will, however, be found impossible to define accurately on a map, from this information alone, the area occupied by each formation. Not only would such a plan involve more labour than the methods described, of walking over the ground and following the actual boundaries, but it would be liable to local error, arising from sudden changes of dip or the occurrence of faults between the points where the particulars were obtained.

The boundary lines of the older rocks are traced and laid down in a manner similar to that detailed in the preceding examples, being equally governed by the con-

ditions of dip and shape of the ground, and yielding similar surface evidence. But they are much more likely than those of newer date to be faulted and contorted, and their dip seldom continues unaltered for any distance, either in amount or direction.

Faults are not often seen in actual section, except in mines and fresh railway-cuttings. They may or may not produce a definite surface feature or give rise to a series of springs; such results, of course, depend on the similarity or difference, in point of hardness and composition, of the rocks thus brought into contact with each other. The existence of a fault (*i.e.* of a fracture and displacement of the rocks) is first suspected from certain signs at the surface. It is then, for the moment, assumed, and the evidence is examined from a point of view favourable to its occurrence. If all the observations be found thus to fit in, and to be accounted for by such an explanation better than by any other, it may be considered that the presence of a fault is fairly established and will be corroborated by any additional evidence. When once discovered, a fault may be easily traced by some one or more methods of tracing boundaries, which vary in each instance according to the nature of the indications most readily obtainable. It will probably extend in a more or less direct line, and sometimes will divide to form two branches. Other lines of fracture may run into it, in a direction transverse to that of the main fault and generally almost at right angles.

RULES for detecting Faults, and distinguishing them, when unseen, from Flexures and Unconformities.

The presence of a fault may be surmised from :—

Perspective Diagrams of Pits, cut back to the edge of an Outcrop, to illustrate the Rules for detecting and distinguishing Faults, Flexures, and Unconformities.

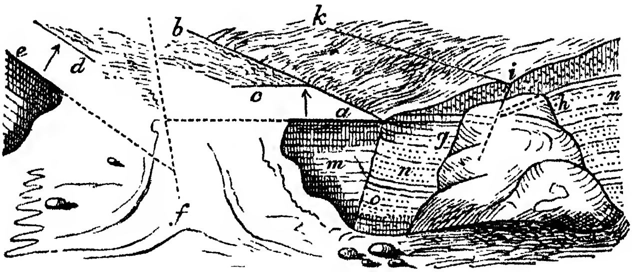

Fig. 10.

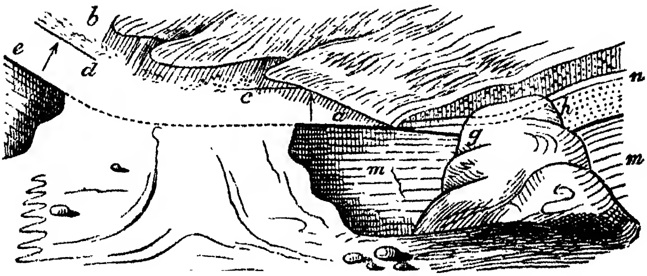

Fig. 11.

a, c, d, e, Outcrop of a bed with its line of strike suddenly diverted; *a—e* (black line), Thin edge of ditto; *a—b*, Line of Fault; *k—i.* ditto; *b—f* (dotted line), probable ditto.

1. *The unexpected termination of an outcrop, or the failure in continuity of definite bands.* (See *a* figure 10.)

   The only other explanation of an abrupt termination, at the surface, of an outcrop or definite bed, is that it passes under the rocks of a newer and unconformable formation, as at *a*, figure 11. But a fault, although unseen, may be distinguished from unconformity, as the true boundary-lines of all beds are governed by dip and surface feature (*a*—*b*, figure 11). On the other hand, a fracture will follow a straighter line, and will be quite independent of those conditions (*a*—*b*, figure 10).

2. *A sudden change in the strike of rocks, consequent on and indicating an abrupt alteration in direction of the dip, that may or may not be seen in section* (*a*—*c*, *d*—*e*, figure 10).

   Accurate mapping of the boundary-lines will decide whether or not there is a fault in the direction of the dotted line *b*—*f*. Although changes in direction of dip and strike occur in unfractured as well as in fractured beds, and sometimes very rapidly, they never do so with absolute abruptness. If the beds are sharply bent, but still remain unbroken, the changing dip (and consequent strike) cannot form an angle, but will describe, at the point of change, a curve tangential to the straighter portions between which it intervenes (dotted line *c*—*d*, figure 11).

3. *A great difference in amount of dips observed in rocks of the same age, in sections so near to each*

other, that a bend in the rocks is less probable than a fracture; for instance, at *g* and *h*, figure 10, the intervening part not being exposed.

This may arise from sharp flexure, without fracture (*g—h*, figure 11), but if there is a considerable change in direction as well as in amount of dip, the existence of a fault (*i—k*) between the observed adjacent points is certain. (See also Rule 2.)

4. *Dips which, if observed in rocks of different ages in adjacent sections, could not be continued without bringing the dissimilar rocks into vertical contact;* as in the two series of rocks, *m* and *n*, on opposite sides of the fault *a—b*, figure 10.

Such dips may be either opposed, transverse, or coincident in direction. If the sections are not in close proximity, the observations may indicate unconformity, and not fracture, as between the same two series of rocks in figure 11, but the boundary-lines will afford a clue to the right explanation.

5. *Absence, from between the outcrops of two formations, of any other formation which usually intervenes; or, the occurrence, between outcrops, of any formation which thus is not in its normal position.*

This may indicate either a fault or an unconformity, which it is will be decided by the boundaries.

6. *The non-appearance or the re-appearance of any bed which can be identified, where its previously observed dip in the first case would, or in the second would not, lead to its being expected.*

This may indicate either a fault or a flexure, to be determined by Rule 1 or 3.

7. *An otherwise unaccountable change of surface feature.*

This is not (nor are any of the phenomena described in the preceding rules) actual proof of a fault without the evidence afforded by accurately surveyed outcrops; but in obscure areas they will prove useful guides in the right direction.

It will be gathered from these rules that the chief surface indications of disturbance are :—of Flexure, a gradual change in the line of strike; of Unconformity, the approach towards each other of boundary-lines which follow somewhat the shape of the ground; of a Fault, the approach of similar lines that end against another, scarcely, if at all, affected by the physical contours. (Rules 1 and 2). The presence or absence of certain rocks indicates, as the case may be, either a Fault, a Flexure, or an Unconformity (Rules 5 and 6).

A shift in outcrop is of course the evidence to prove the existence of an unseen fault. It may well have been suspected from the occurrence of any of the conditions upon which the rules are based, but then its actual line must be determined from dip, surface feature, and other evidence. A pencil-line should be drawn provisionally on the map, in the probable direction of the fracture, passing through the broken ends of the outcrop, as nearly as these can be ascertained. Other broken outcrops, of higher or lower beds, may occur, and if in about the same line, they are due probably to a continuation of the same fracture. All the indications must be examined, for and against the assumed fault; if in favour

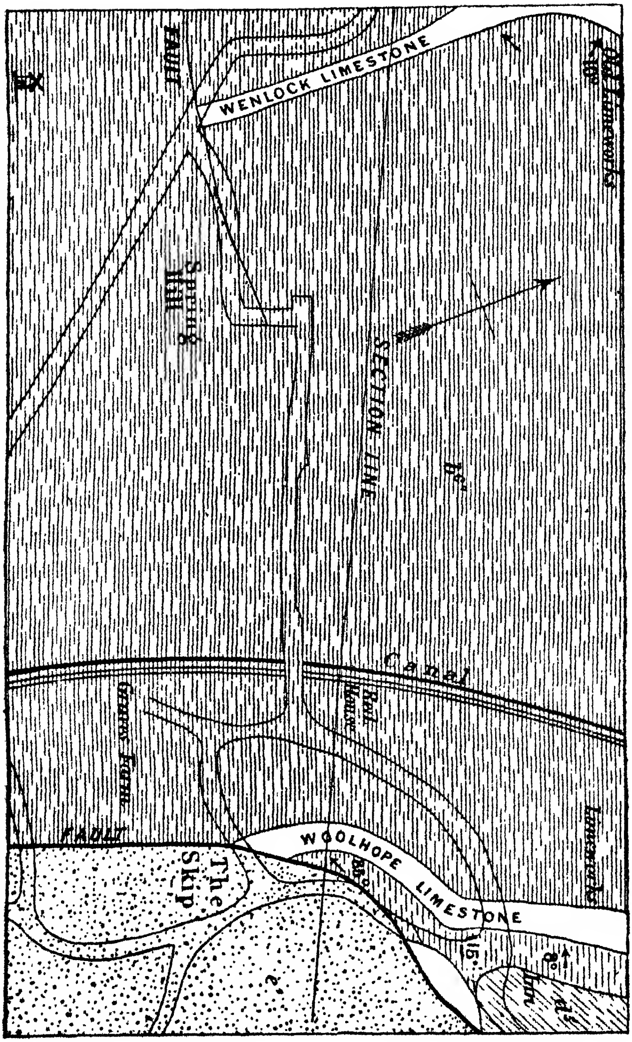

Fig. 12. Area of palæozoic rocks, to illustrate the examples of tracing boundaries and faults. E. side; joins fig. 13.

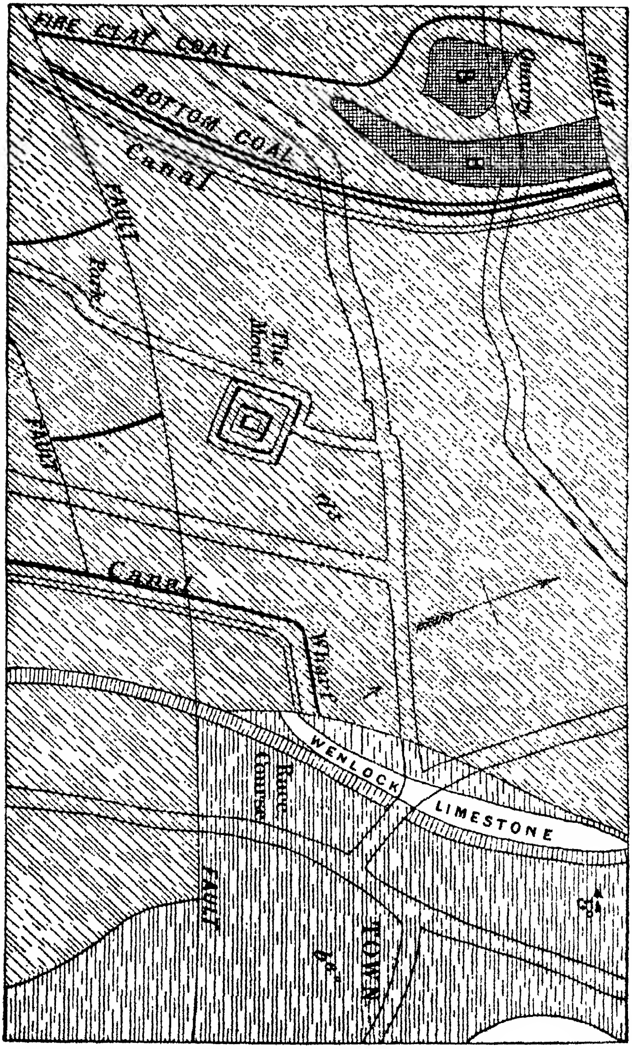

Fig. 13. Area of palæozoic rocks, to illustrate the examples of tracing boundaries and faults. W. side; joins fig. 12.

of its occurrence, the actual line can be readily traced, and the broken outcrops, hitherto perhaps very puzzling, can be mapped with ease. If not, there must be something wrong, either in the observations or in the deductions from them: there is no fault at all, or it has been laid down in the wrong place or direction. When the presence of a fault has been surmised from any of the conditions described in the rules, and tested by them, and by any other evidence that can be obtained, it may still not be considered as actually proved without the concurring testimony of a shift in the outcrop of the bed or formation.

The beds which suddenly rise towards their outcrop are on the downthrow side of a fault, should one be proved to exist (*o*, figure 10); those suddenly dipping, or increasing in dip, towards it, are on the upthrow side. But should any of the upper beds, which have cropped out in a district, set in again, and be found dipping in an opposite direction, an anticlinal is indicated, which may, or may not, be actually broken. It follows that:—

Anticlinals, and synclinals also, whether faulted or not, are indicated by the same beds dipping in opposite directions away from the line of their strike, which coincides with the line of greatest elevation.

These opposing dips increase or decrease in amount towards the outcrop, according to the greater or less extent of denudation which the beds have undergone; the steepest dip, of course, being at the centre of the uniclinal curve, where the synclinal ends and the anticlinal commences.

Examples of tracing boundaries and faults. The area which has been selected as an illustration of the method of surveying faulted palæozoic rocks is a small portion, three miles long by one mile wide, of an English coalfield. The Coal Measures occur at the surface in contact with some still more ancient sedimentary rocks, with a formation newer than themselves, and with some intrusive igneous masses. The facts thus briefly stated may be supposed to have been observed in a preliminary visit to the quarries of the neighbourhood, during which the shape of the country has also received our attention. A map of the district is given in two slips (figures 12 and 13, the western side of the former joining on to the eastern side of the latter), all minor topographical details being, for sake of clearness, omitted. The slope of the country is observed to be down from the east, some streams rising from the higher ground in that direction, this fall being varied by several local undulations, and intersected by small valleys occupied by streams. The eastern slip, figure 12, is traversed by two streams running in the direction of the general fall of the ground, both of which, near its margin, bend suddenly to the south; one leaves the area entirely, the other passes across that of figure 13, just beyond the town; between these two streams some relatively high ground is noticed. Another stream further west in figure 13, crosses the map in the same direction; a ridge of high ground occurs between it and that which runs by the town, whilst beyond it the country rises with more abruptness, especially in the N.W. corner. On the flanks of these higher lands, we should expect to find any boundary-lines that may occur (except those

boundaries beneath it perhaps less exact, and certainly more difficult.

The railway being in a cutting, and revealing, as previously ascertained, a section of beds of Silurian age, offers a good starting-point. The west slope of the cutting shows some solid, concretionary, and flaggy calcareous beds, dipping W., with many calcareous nodules, concretions, and small flaggy beds above, and similar beds with a tough grey clay below. These beds of limestone would appear to have a thickness of about 12 feet, but this cannot be correctly ascertained, owing to the talus of fallen material. The notes of this section and of others taken during the survey of the area, are given in chap. ii., Part ii., and those relating to the fossils collected from the beds in Part iv.

The lower boundary of the limestone beds nearly coincides with the railway, as very little of them is seen on the eastern slope of the cutting. The upper line is traced by feature and surface-evidence, all indications of the limestones and flaggy beds above ending abruptly near the Wharf. These beds have also been seen now and then for a short distance westward, from the bridge, but are then succeeded by sandstone containing pebbles, and this by some bluish-grey shales with limestone partings; the latter are observed in a small exposure by the roadside N. of the wharf, and are there found to be dipping N.N.W., that is, in a direction differing from that of the limestone by about 50° (see Rule 4, p. 68). The boundary of these shales is followed and drawn, as accurately as the circumstances will allow, from the wharf just where the limestones were lost, across the road at some distance from them, and beyond this point

it again gradually approaches, and eventually touches that of the limestone. The line when drawn evidently indicates an unconformity between the shales and the Silurian beds, which is further proved to exist by the change in the direction of their dip; these indications might have been due to a fault between the formations, but of this there is no evidence, while the boundary-lines are in favour of the former proposition.

The area north of the high road is then traversed in the usual manner, but not much evidence is obtained. Just beyond the map, however, by the road leading north from the railway-bridge, a section shows 6 feet of Coal Measures overlying Silurian shale, and this superposition proves the correctness of the inference in regard to the unconformity previously assumed from the boundary-lines. Throughout this part, north of the high-road, there is no other section, but ample surface evidence is found of sandy beds, succeeded westward by shales with occasional bands of ironstone; no coal-crops, are, however, observed.

Crossing the canal we ascend the rising ground in the N.W. corner of the sheet, having first noticed on the slope some traces of an outcropping bed of coal. Part way up the hill, and in a small cutting made for a tram-way, Coal Measure shales, with ironstone, are seen lying nearly horizontal and traversed diagonally by a small dyke of white trap-rock (? altered Basalt), but this being one foot only in thickness cannot be shown on the map. The tramway leads down from a large quarry excavated in what was once a slightly prominent mound, but the greater part of it has now been quarried away. The rock here exposed has a columnar structure, is

crystalline, rather cross-grained, so hard as to be scratched only with difficulty, does not effervesce with acid, is nearly black but weathers brown on exposed surfaces, and it breaks with a conchoidal fracture. Judged by these characters and its occurrence in the midst of the Coal Measures, it is determined to be an eruptive (or intrusive) mass, most probably of Dolerite. (See Part III., chap. iii.)

On one side of the quarry the black shales of the Coal Measures are seen to rest on the trap-rock which immediately below them consists chiefly of balls of the rock bedded in a mass of clay. The quarry almost covers the area of igneous rock here exposed at the surface, but lower down the hill the clay containing balls of the basaltic material re-appears for a short distance and then disappears again beneath the Coal Measures. The boundary-lines of the mass or masses of trap are then drawn, their surface being limited, or nearly so, by the quarry as regards the upper portion; that lower down is readily traced by the change of feature caused by the hard rock standing out from the more easily denuded Coal Measures; on the upper side is an accumulation of rain-wash, but not sufficient to obliterate the indication.

Just beyond the quarry a coal-seam crops to the surface, and is easily followed northwards, until it ends suddenly, as did the mass of dolerite, near the northern edge of the map; a fault probably cuts off both the outcrops, but this may be left for the present. The outcropping coal-seam sweeps round the base of trap-rock, then suddenly resumes its southerly course, which it follows in a nearly straight line almost to the margin

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similarly laid down, one being just out of the slip, and these are found to be on a line nearly parallel with that of the assumed fracture, which is most likely a second fault running in the same direction.

The boundary of the Coal Measures was left by the wharf, where it appeared as if it would follow the railway, or nearly so; but such is not the case. Crossing the line we continue to find the same strata (where it is possible to get at them beneath the drift-gravel) almost to the edge of the slip, where the Silurian beds are again discovered, and the boundary between the two formations is with some trouble traced in a northerly direction. This boundary abruptly changes its direction, crossing the road at right angles and towards the point where it first left the railway in a similar unexpected manner. This westerly trend in the line of division between the Coal Measures and Silurian rocks when drawn is found to be pointing directly towards the broken ends of the two coal-seams, south of The Moat, through which a suspected line of fault was drawn in pencil and left for further evidence. Nothing could well be more conclusive than this; and a line of fracture running through all the points in question may be considered as established.

The two coal-seams on the south side of this fault would appear to be the lowest in the series as here represented; so also would those beyond the stream on the north side of the dislocation—because no other outcrops occur between them and the boundary of the Measures where they rest unconformably upon the Silurians. Therefore they are most probably identical beds, those on the south side having been thrown down

by the dislocation, which shifts their outcrop to the east, as the beds are rising in an easterly direction. The greater width on the map between their outcrop is due partly to the downthrow having altered their dip, and partly to a difference in surface feature.

On the north of the town and east of the road are some large old quarries (fig. 12), in which a limestone was formerly worked, dipping westerly 10°. This limestone must be continued under the town to the southward, being however concealed from view by a very thick capping of gravel, and is doubtless cut off by the fault which runs east and west from The Moat, and probably extends some distance into, if not almost across, the second slip. Owing to the gravel covering and the homogeneous nature of the shales, no sections whatever are seen in the underlying rocks in passing down the road to the south-east, and over the ground on either hand. Following the small stream and the bank of the canal towards Graves Farm, we find in the latter some cuttings in Silurian shale as nearly horizontal as possible, and containing many characteristic fossils. We cross the bridge and traverse the area on the other side of the canal, suddenly losing all traces of the shales and coming upon some red sandstones and marls of the Permian system. This change takes place everywhere along a north and south line, repeatedly crossed in walking over the ground, to the shape of which it does not, however, conform. From this circumstance we are led to surmise the presence of a fault, as the Silurian and Permian rocks can be brought in contact only by a fault or an unconformity (see Rule 5, p. 68). These Permian beds have an easterly dip, but its exact

amount or direction is not to be ascertained in the small ditch–and roadside–sections only that are met with. A short distance north of The Skip there is a pit in thin layers of impure limestone, fossiliferous (see Note *o*), with shales above full of calcareous lumps and nodules, all dipping W. at an angle of 35°. As the shales are horizontal by the canal not far to the W., this section shows a change which is very sudden, and indicates either a fault or flexure in the beds. The limestone ends abruptly against the Permians, or it may possibly be cut off by an extension of the east and west fault along the dotted line on the map, figure 12 (see Rule 1, p. 67), a supposition which is strengthened by the non-occurrence of any of the limestones to the south of that line.

We trace this limestone in a N. by E. direction, and find that it occupies only a narrow belt of surface and that some lower shales intervene between it and the Permians, by crossing and recrossing the lines of outcrop and boundary. Its direction changes to nearly N. before it reaches the next road, and its dip is observed to have decreased to 15°; still further north it is 8° only, as seen in the excavation at the Limeworks, which presents a good section. See Note *p*, chap. ii., Part II.

On the east the shales which have risen from beneath the limestone are hidden under the Coal Measures resting unconformably upon them, and occupying the N.E. corner of the slip, but the ground being wet and marshy the position of the line of division is somewhat uncertain.

In mineral character the last limestone followed much resembles that of Woolhope in Herefordshire,

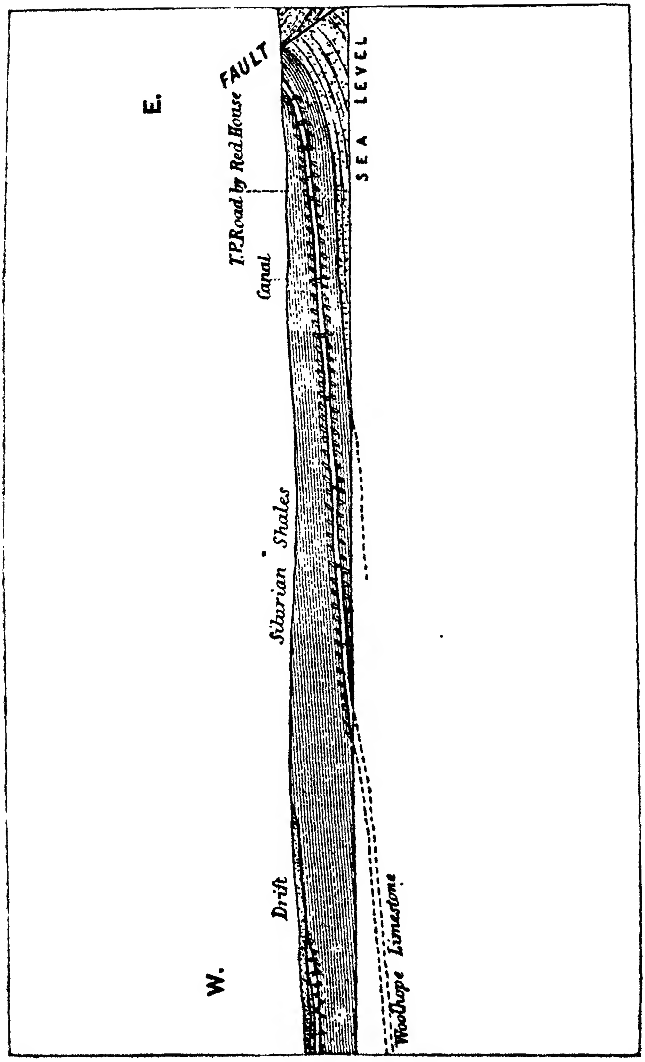

Fig. 14. Section to illustrate the geology of the area of palæozoic rocks, shown in fig. 12.

which lies at the junction of the Wenlock and Llandovery rocks. If it be at or near the base of the Wenlock rocks, we ought to have the Llandovery sandstone rising out immediately to the east of the limestone; and we find that in a small old quarry S.E. of the limeworks a pale yellow or brown sandstone is actually exposed, in some places nearly white and purely quartzose, in others stained with ferruginous bands forming concentric rings. Some parts of it are highly fossiliferous, and the species determined show that the bed is the equivalent of the Llandovery sandstone. This sandstone is cut off by the Permian marls, the line of fault between them and the Silurian rocks here assuming a N.E. direction, and it passes to the north beneath the overlying unconformable Coal Measures.

A description of the beds passed through in sinking the shaft of a colliery just beyond the N.W. corner of the map was obtained, and is in part given amongst the notes relating to this area on p. 116. From this it will be seen that the first and second coal crops traced are those of the 'Fire Clay Coal' and the 'Bottom Coal,' the latter dividing, as was surmised and as mapped, having a small thickness of carbonaceous shale between its upper and lower portions.

PART II.

SECTIONS

CHAPTER I.

SECTIONS.

Dip—Strike—Table of Dip, depth and thickness—Clinometer —To find direction of Dip—To find amount of Dip.

Dip.—It is but rarely that strata are found in an absolutely horizontal position; indeed, it is mainly owing to their inclination that so many formations are now seen outcropping at the surface of the earth. A knowledge of the angle at which the beds are inclined is of great service to the geologist when drawing sections to show the structure of a district, and in enabling him to affirm, within reasonable bounds, the thickness of a deposit or the depth at which it will be found in any specified locality. The angle at which a bed deviates from a horizontal plane is called its 'angle of dip,' a term which is, however, generally abbreviated, the word 'dip' only being employed. A line passing from any one point on the surface of a bed through another point

which is the lowest possible at that distance from the first, in other words the line of greatest steepness, represents the dip's direction.

Strike, Stretch or Trend.—A line crossing at right angles that of the line of dip or greatest steepness must necessarily be horizontal, and would therefore coincide with the edge of a bed that might come to the surface in a perfectly level tract of country. Such tracts seldom occur, and owing to the general unevenness of the surface an outcrop can rarely be represented by a straight line, although the dip may continue the same for a long distance. But a line through all the points, situated at the same level on a boundary, will always be found to lie at right angles to the dip; and this line is called the 'line of strike,' or shortly 'strike,' of a bed or a formation.

It will be seen from a consideration of the above that as the 'direction of dip' varies, so also will the 'line of strike,' which in the main corresponds to the outcrop of a formation:—inversely, as the 'line of strike' or general outcrop varies, so also will the 'direction of dip' in an equal proportion. We may at all times be certain of this, even when no ocular evidence is forthcoming, and the fact will frequently be found of service in geological investigations.

As the amount of 'dip' varies, so does the breadth of level surface that the outcrop of a bed of constant thickness will occupy. This is a very useful thing to remember in geological surveying, also in drawing sections where the evidence is scanty, especially as the actual slope of the ground is ascertained for the latter purpose. And it follows that the value of any two of

the three factors tabulated below being known, that of the third can at once be ascertained.

$$\left.\begin{array}{l}\text{1. The thickness,}\\ \text{2. The dip,}\\ \text{3. The breadth of outcrop,}\end{array}\right\}\text{ of a bed or formation.}$$

For examples see p. 91.

The following table of Dip, Depth and Thickness has been prepared for the purpose of approximately giving the amount of rise or fall of the ground within a certain distance, the depth to which a bed with an ascertained dip will have descended at any particular spot, and the consequent thickness of the beds above it. The first column gives the angle of inclination of the beds or of the surface, the second the cotangent of the angle, which is also the proportionate incline, whether of rise or fall, as the case may be. Those which follow show the number of yards of rise or fall in a mile at each angle of inclination, the vertical depth to a bed in a horizontal distance of 100 from its outcrop, and the actual thickness of the beds above, measured, not vertically, but at right angles to their plane of stratification. This distance of 100 is measured along a horizontal surface in the direction of the dip, and allowance has of course to be made for the rise or fall of the ground, if uneven, between the points.

TABLE OF DIP, DEPTH, AND THICKNESS.

Amount of Dip.	Cotangent of angle of Dip.	Approximate Proportionate Incline.	Yards of Rise or Fall in 1 mile.	Depth from Surface in a Distance of 100.	Thickness of Beds at right angles.
0°	Infinity.				
1°	57·29	1 in 57·	31	1·75	1·75
2°	28·6363	1 in 28½	61	3·5	3·5
3°	19·0811	1 in 19·	92	5·25	5·25
4°	14·3007	1 in 14½	126	7·	7·
5°	11·4301	1 in 11½	155	8·75	8·75
6°	9·5144	1 in 9½	185	10·5	10·5
7°	8·1443	1 in 8·	217	12·5	12·25
8°	7·1154	1 in 7·	249	14·	13·75
9°	6·3138	1 in 6·5	279	16·	15·75
10°	5·6713	1 in 5½	314	17·5	17·25
11°	5·1445	1 in 5·	345	19·5	19·25
12°	4·7046	1 in 4½	391	21·25	20·75
13°	4·3315			23·25	22·5
14°	4·0108	1 in 4·	440	25·	24·
15°	3·7321			26·75	25·5
16°	3·4874	1 in 3½		28·5	27·
17°	3·2709			30·	28·25
18°	3·0777	1 in 3·		32·25	30·25
19°	2·9042			34·5	32·
20°	2·7475			36·5	33·5
21°	2·6051	1 in 2½		38·5	35·
22°	2·4751			40·	36·
23°	2·3559			42·25	37·75
24°	2·2460			44·5	39·5
25°	2·1445			46·75	41·25
26°	2·0503	1 in 2·		47·75	41·75
27°	1·9626			51·	44·25
28°	1·8807			53·25	45·75

TABLE OF DIP, DEPTH, AND THICKNESS—*continued.*

Amount of Dip.	Cotangent of angle of Dip.	Approximate Proportionate Incline.	Yards of Rise or Fall in 1 mile.	Depth from Surface in a Distance of 100.	Thickness of Beds at right angles.
29°	1·8040	1 in 2·		55·5	47·25
30°	1·7321	1 in $1\frac{1}{2}$		58·	49·
31°	1·6643			60·25	50·5
32°	1·6003			62·5	51·75
33°	1·5399			65·	53·25
34°	1·4826			67·5	54·75
35°	1·4281			70·	56·25
36°	1·3764			72·5	57·75
37°	1·3270			75·25	59·5
38°	1·2799			78·	61·
39°	1·2349	1 in 1·		81·25	63·
40°	1·1918			84·	64·5
41°	1·1504			87·	65·75
42°	1·1106			90·	67·75
43°	1·0724			93·	69·25
44°	1·0355			96.	70·25
45°	1·			100·	71·
46°	·9657			104·	72·
47°	·9325			107·	73·25
48°	·9004			111·	74·25
49°	·8693			115·	75·5
50°	·8391			119·	77·
51°	·8098			123·	78·
52°	·7813			128·	79·
53°	·7536			133·	80·
54°	·7265			137·	81·
55°	·7002			143·	82·
56°	·6745			150·	83·
57°	·6494			154·	83·25
58°	·6249			161·	84·5
59°	·6009			166·	85·5

TABLE OF DIP, DEPTH, AND THICKNESS—*continued.*

Amount of Dip.	Cotangent of angle of Dip.	Approximate Proportionate Incline.	Yards of Rise or Fall in 1 mile.	Depth from Surface in a Distance of 100.	Thickness of Beds at right angles.
60°	·5774			172·5	86·5
61°	·5543			180·	87·
62°	·5317			188·	88·
63°	·5095			200·	89·
64°	·4877			205·	90·
65°	·4663			213·	90·5
66°	·4452			224·	91·
67°	·4245			235·	91·5
68°	·4040			250·	92·
69°	·3839			260·	93·
70°	·3640			275·	94·
71°	·3443			300·	94·5
72°	·3249			308·	95·
73°	·3057			327·	95·5
74°	·2867			345·	96·
75°	·2679			370·	96 5
76°	·2493			400·	97·
77°	·2309			433·	97·5
78°	·2126			476·	97·5
79°	·1944			515·	98·
80°	·1763			570·	98·5
81°	·1584			633·	98·5
82°	·1405			714·	99·
83°	·1228			813·	99·
84°	·1051			1000·	99·5
85°	·0875			1140·	99·5
86°	·0699			1430·	99·5
87°	·0523			1912·	100·
88°	·0349			2865·	100·
89°	·0175			5714·	100·
90°	·0000			—	100·

Examples of the Use of the Table.

1. The outcrop, in a level district, of a definite bed is observed in a quarry, where it is found to dip E. at an angle of 14°.

This bed would be found, if its dip remains unaltered, 100 yards east from the quarry at a depth of 25 yards= 75 feet: the beds above it would have an actual thickness of 24 yards=72 feet. See fifth and sixth columns, opposite amount of dip 14°.

2. The outcrop of the same bed with the same dip is observed in a district where the surface rises in the direction of the dip at an angle of 10°.

The bed would be found, 100 yards E. at a depth of 75 feet, as before, plus the rise in the ground between, which in 100 yards, at the rate of 314 yards in a mile, is $17\frac{2}{3}$ yards=53 feet:—75+53=128 feet. See the fourth column, opposite dip 10°.

If the ground were falling, instead of rising, at an angle of 10° in the direction of the dip, the bed would be met with at 75—53=22 feet.

The following examples, 3^a, 3^b, 3^c, have reference to the proposition on page 86.

3^a. A bed or formation is known to be 36 yards in thickness, and to dip at an angle of 14°. In 100 yards of outcrop it would, at that dip, have a thickness of 24 yards only, therefore its outcrop is (24 : 36 :: 100) :: 150 yards. See sixth column opposite dip 14°.

3^b. The thickness is known to be 36 yards, as before, and the level outcrop 150 yards. In 100 yards ($\frac{2}{3}$ of 150), the thickness would be 24 yards, which corresponds to a dip of 14°.

3'. The dip of the bed is 14°, its outcrop 150 yards: in 100 yards at 14° the thickness would be 24 yards, therefore in 150 it is 36 yards.

Clinometer.—It matters little by what kind of instrument the dip of strata is measured in the field, so long as it indicates, with a fair approach to accuracy, the amount of inclination. All clinometers must possess a graduated arc, and either a pendant hanging perpendicularly, or a spirit-level lying horizontally, which shall show the number of degrees that the chord of the arc deviates to either hand from a horizontal plane. A

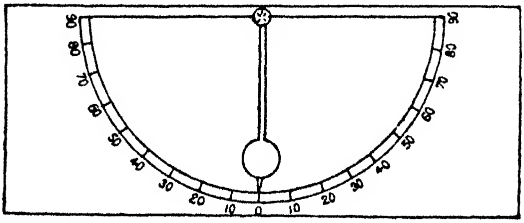

Fig. 15.

simple form of clinometer is shown in fig. 15; but as portability is a great desideratum, and as the pocket-compass, which should be the geologist's constant companion, possesses a graduated circle, the one instrument may well be made to answer the two purposes. This is effected by the addition of the part shown by the dotted lines in fig. 1, page 10, and of a small pendant swung from the point which also carries the magnetic needle. When the two instruments are thus combined, the circumference is divided not only into cardinal and intermediate points, but also into degrees numbered to the right and left of zero. This point is just over the centre of the clinometer base, the figures run up to 90°

on either side and then back to zero at the top, so that the instrument can be used inverted, and placed to the under-side of a bed when required.

To take the dip of a bed exposed in a pit, quarry, or elsewhere, clear away the material from its upper surface in a part as flat as can be found, and which follows as nearly as the eye can detect the general line of stratification. Place the clinometer on this, or what is a better plan, on a stick or hammer-handle first laid on the rock; this being of greater length than the instrument is less liable to error from an irregularity of surface. See that the clinometer is directed along the steepest part of the cleared surface (which is probably not in a line with the face of the pit), also that the pendant is swinging freely at the time; when it comes to rest, read off the number of degrees and make a note of the result. In some instances, as beneath a ledge of rock, in a mine, or in a cavern, it is more convenient to take the dip from the under-surface of a bed, when by using the upper edge of an ordinary clinometer, or by the inversion of the compass-form of instrument, the same result may be obtained. In other cases neither the upper- nor under-surface of a bed can be got at without much labour, when the hammer-handle or stick should be held along the exposed face, or edge, as nearly as may be in the line of the bed, and the clinometer placed thereon. Again, beds may be exposed in cliffs or deep pits, at such a height or in such a position as not to be readily accessible; under these circumstances, the observer should take his stand at a good distance from the face of the cliff or quarry, at right angles, or thereabouts, to the spot where he wishes the dip to be deter-

mined. Holding the instrument steadily before his eye, he inclines it until its edge coincides with that of the bed which is being observed, and then reads off the angle indicated as quickly as possible, and before the position of the clinometer is shifted; to ensure accuracy by this method, two or more observations should be made and the results compared.

In the two last-named instances—the exposed edge, accessible and inaccessible—the *apparent* dip is taken; this may or may not be the true dip, which can be greater, but cannot be less, than that of the exposure. Apparent dip varies from the true dip as the exposed face differs from the dip's direction, until it coincides with the strike, when no dip whatever is discernible. Wherever possible, and unless the observer be certain that he is getting the true dip, he should make two observations, the direction of one at a considerable angle with that of the other, from which the true dip can be ascertained.

Both the amount and direction of the true dip may be calculated from any two observed dips; but for all practical purposes the results obtained by the methods given in the following pages are sufficiently accurate and much more expeditious.

The final results of observations taken with the clinometer—the amount and direction of the dip (if any) of a bed or formation—are shown on the map by symbols such as are given in the table at page 44, drawn in vacant spaces as near as possible to the spot where the sections are exposed.

To find direction of Dip, by diagram.—When the amount and direction of two lines of apparent dip are

known, the direction of the true dip may readily be found by the following Rule:—

RULE. *Case* 1.—When both the observed dips incline from or towards the angle enclosed by their lines, fig. 16, the true dip is at right angles to a line *a b* laid down by the following method:

Set off from the angle on each of the two lines of apparent dip a number of units corresponding to the number of degrees of dip observed along the *other* line, and connect the two points by a line *a b*.

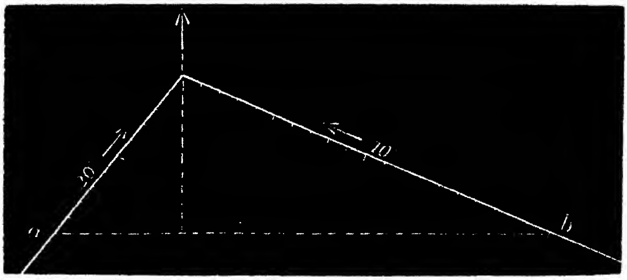

Fig. 16.

This line coincides with the strike, and is consequently at right angles to the true dip's direction. If the observed dips incline towards the angle of the quarry the dip is from the observer, and *vice versâ.*

Case 2.—When one observed dip inclines from, and the other towards, the angle enclosed by their lines (fig. 17), prolong one of those lines, and in the angle thus formed work out the dip by the method given above, for both apparent dips will then run either from or towards the angle.

This method is valuable for finding the dip, or dips, and possibly faults, from three or more points on the outcrop of a bed where no sections are discovered. The

position and relative heights of such points must be ascertained, when the lines connecting them may be

Fig. 17.

treated as the faces of a quarry, and the dip worked out in the manner described.

-The foregoing Rules were first published by the Author in a communication to the 'Geological Magazine' for May, 1876 (p. 236), and gave rise to considerable discussion at the time.

There is a slight error arising from the difference between the circular measure of an angle and the tangent of that angle, but in most cases it may be disregarded.

Mr. O. Fisher, who kindly subjected the method suggested to careful examination, wrote to say that the Rule was correct for small dips for all practical purposes, and to suggest the following mode of applying it in Case 2.

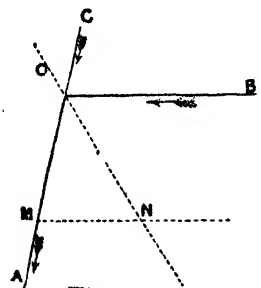

Fig. 18.

'Draw from any point M in the quarry, M N parallel to the face O B, and set off M N so that dip in O B : dip in O A : : O M : M N. Then O N is the direction of the strike.'

In the 'Geological Magazine' for June, 1876, Mr. H. G. Day suggests, 'instead of "the number of degrees of dip," write "the tangent of the angle of apparent dip," a method of course more exact, but involving the necessity of having at

hand a table of tangents. He adds that 'the truth of the principle so modified is obvious from the following considerations: If along the line *b*, the rise is 1 in 20; and along the line *a*, 1 in 10; then, taking 20 units along one line, and 10 along the other, we arrive at the horizontal line in the plane; *i. e.*, at the line of strike.'

In the July number of the same magazine, Mr. E. Hill states the Rule in a similar form: 'Set off along each line lengths proportional to the tangent of the other dip (or to the cotangent of its own). Join the ends of these lengths; the joining line will be the direction of the strike, the perpendicular to it from the angle will be the direction of the dip.' Mr. Hill continues: 'If cotangents have been used, the length of this perpendicular is proportional to the cotangent of the true dip, whose magnitude as well as direction will thus be determined by one construction.'

The last proposition is put in a very simple form by Mr. A. H. Green, in the magazine for Aug., 1876: 'Let the dips observed along two lines A B, A C, be 1 in *m* and 1 in *n*; make A B *m* units, A C *n* units in length; join B C, and draw A D perpendicular to B C.

'Then A D is the direction of the full dip, and if A D contains *d* units of length, the full dip is 1 in *d*.'

The Rule stands as it was first published, it being considered that the error which arises from using the number of degrees of dip instead of their tangents or cotangents is too slight, except in the case of high angles, to be of practical importance; it is easily remembered and applied in the field, where tables of tangents may not be available. But in certain instances greater accuracy is desirable, therefore a table of cotangents is given at page 88; and the following proof of the correctness of the proposition, in its more accurate form, has been kindly supplied to the author by Lieutenant L. D. Sampson, R.N.

'Mathematical Investigation, concerning Mr. Penning's Rule for finding the true dip from two apparent dips observed in quarries or elsewhere.

'*Case* 1.—In which the observed 'dips' are both towards (as in fig. 19), or both from, the angle of the quarry.

'*Construction.* Fig. 19.—Take the points B and C on the observed lines of dip and Z in the vertical line of the angle of the quarry, B C and Z being in the same horizontal plane.

'Join B C, and from Z let fall Z R perpendicular to B C or B C produced and join R O.

'Then we have the angles B Z O, C Z O, R Z O, Z R B, and Z R C each = 90°. Then also B C will be the strike of the bed in the plane B Z C R, and Z R will be the direction of, and Z R O the amount of the true dip.

'*Proof.*—In the triangles Z R O, Z B O and Z C O let Δ Δ' Δ'' represent the dips Z R O, Z B O, Z C O, respectively.

$$\text{then } \frac{\cot. \Delta'}{\cot. \Delta''} = \frac{\frac{ZB}{ZO}}{\frac{ZC}{ZO}} = \frac{ZB}{ZC} \quad - \quad - \quad - \quad (\alpha)$$

$$\text{also } \frac{\cot. \Delta}{\cot. \Delta'} = \frac{\frac{ZR}{ZO}}{\frac{ZB}{ZO}} = \frac{ZR}{ZB} \quad - \quad - \quad - \quad (\beta)$$

$$\text{also } \frac{\cot. \Delta}{\cot. \Delta''} = \frac{\frac{ZR}{ZO}}{\frac{ZC}{ZO}} = \frac{ZR}{ZC} \quad - \quad - \quad - \quad (\gamma)$$

'Hence from (α) (β) (γ) we see that in the triangles Z B R and Z C R

$$ZR : ZB : ZC :: \cot. \Delta : \cot. \Delta' : \cot. \Delta''$$
$$ZB : ZR : ZC :: \cot. \Delta' : \cot. \Delta : \cot. \Delta''$$

and so on.

'From the above reasoning we see that if we lay off lines representing the directions of the sides of the quarry meeting in the point z (fig. 21), and on them mark off z b and z c proportional to the cotangents of the observed dips Δ', Δ'' respectively, by joining b c and letting fall z r perpendicular to it, we have two triangles z b r, z c r, similar and similarly situated to the triangles Z B R, Z C R.

Diagrams to illustrate the mathematical investigation concerning the author's rule for finding the true dip from two apparent dips observed in quarries or elsewhere.

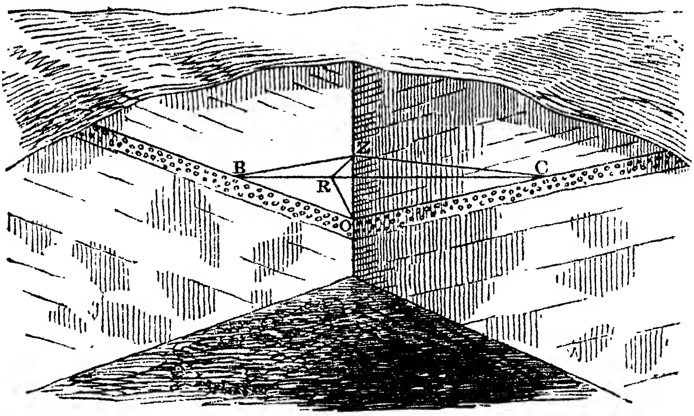

Fig. 19.—Quarry in which the two observed dips are towards the angle.

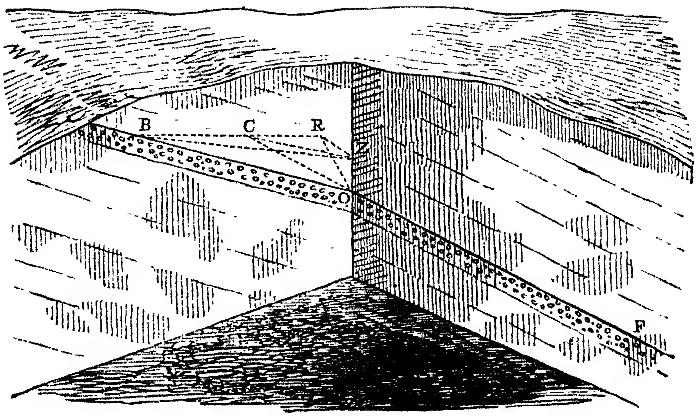

Fig. 20.—Quarry in which one of the observed dips is from, and the other towards, the angle.

Therefore z r will also be proportional to the cotangent of Δ

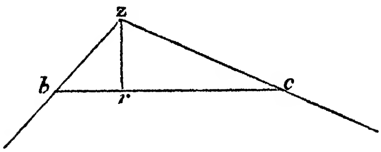

Fig. 21.

the true "dip;" z r will also be the direction of 'dip' and b c of the "strike."

'*Case* 2.—Where one of the observed 'dips' is towards and the other away from the angle of the quarry (as in fig. 20).

'*Construction.*—Imagine one of the lines of "dip" (suppose F O) to be produced into the hill on the opposite side of the quarry: imagine three points in the same horizontal plane, B being on the line E O, C on the produced part of F O, and Z in the vertical line of the angle of the quarry.

'Join B C and from Z let fall Z R perpendicular to B C or B C produced and join R O.

'Then each of angles B Z O, C Z O, R Z O and Z R B is $= 90°$.

'*Proof.*—It may be proved in a manner similar to that in Case 1

$$\text{that } ZR : ZB : ZC :: \cot. \Delta : \cot. \Delta' : \cot. \Delta''$$
$$\text{also } ZB : ZR : ZC :: \cot. \Delta' : \cot. \Delta : \cot. \Delta''$$

and so on.

'Hence, if we lay off the directions z e, z f of the sides of the quarry meeting in the point z thus,

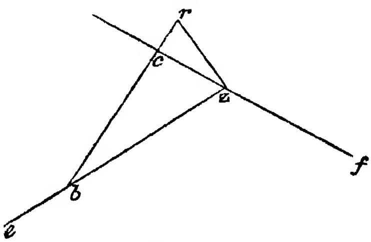

Fig. 22.

and produce one of them (suppose f z) beyond z, and on the

one (e z) not produced we mark off z b proportional to the cotangent of the observed dip Δ' on that side, and if on the produced part of f z we mark off z c proportional to the cotangent of the other observed dip Δ''; by joining b c and producing it, and by letting fall z r perpendicular to it, we have the two triangles z b r, z c r, similar and similarly situated to the triangles Z B R, Z C R.

'Therefore z r will also be proportional to the cotangent of Δ the true dip; z r will also be the direction of the "dip" and b c of the "strike."'

To find amount of Dip, by diagram.—The case in which the direction of dip was found by the preceding Rule, fig. 16, may be taken as an example.

Construct, on one of the lines representing the sides

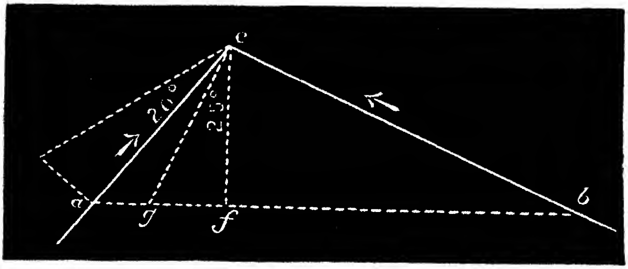

Fig. 23.

of the quarry, a right-angled triangle, the hypotenuse of which shall coincide with the apparent dip on the exposed face where it has been observed (in this case 20°). In the distance *a*—*e* (fig. 23) the bed rises a certain number of feet or inches, and along the line of true dip, *e*—*f*, it of course rises the same number of feet or inches. Set off this amount of rise at right angles to the line of true dip—as in the other case it is at right angles to the

apparent dip—and draw a line from the point g, thus marked off, to the point e, where the rise commences; the angle enclosed (25°) is the measure of the true dip.

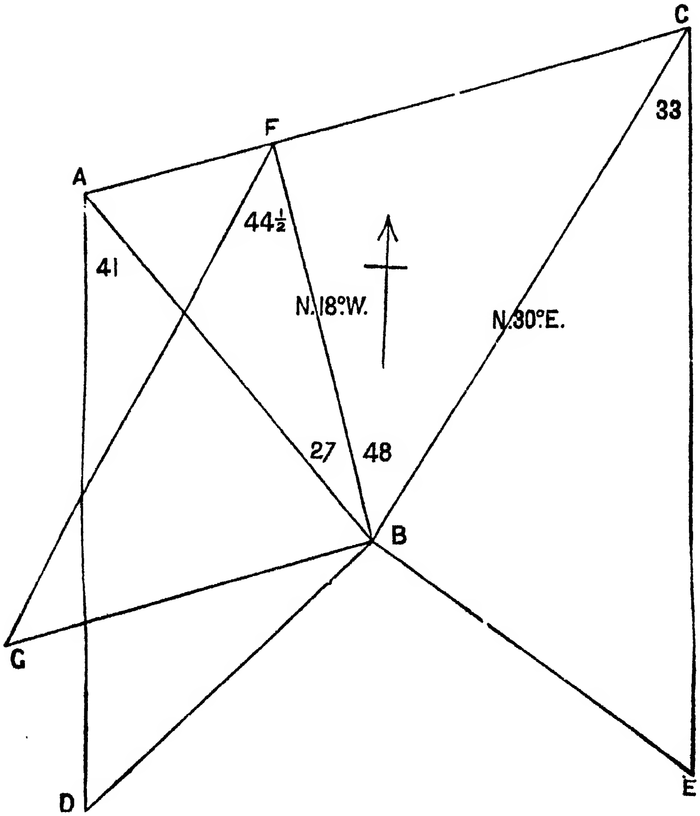

Fig. 24.

The true dip must necessarily be greater than either of the apparent dips, because the bed rises to the same height in a shorter distance.

The following method of finding, by diagram, 'from two apparent dips the full dip and its direction,' published by Mr. W. H. Dalton, of H.M. Geol. Survey, in the 'Geological Magazine,'* will frequently be found serviceable.

Problem.—From two apparent dips to find the full dip and its direction (fig. 24).

Suppose two apparent dips, 41° N.W. and 33° N. 30° E.

Result, 44½° N. 18° W.

Draw B A, B C in the directions of the apparent dips; erect B D, B E vertical to B A, B C respectively, and equal to each other. From D, E, draw D A, E C, making B A D B C E equal to the apparent angles whose direction is shown by B A, B C respectively. Join A C, and draw B F vertical to it. Draw B G parallel to A C, and equal to B E; join F G.

Then B F is the direction of the full dip, and G F B its amount.

Proof.—If A B C be placed horizontally and A B D, B C E, B F G vertically, D G and E will coincide, and D A, G F, E C and A C will be in the plane of stratification, giving the apparent angles at A and C and the full dip at F. In practice, the triangle B G F might be more expeditiously constructed between B F and A C.

* Vol. x., No. 7, p. 332.

CHAPTER II.

SECTIONS—*continued.*

Actual Sections—Vertical Sections—Notes—Ideal Sections—Filling in Geology—Apparent Dip—Downthrow.

Actual Sections.—In the examination of the rocks exposed in quarries, pits, and so on, we make a definite series of observations. On entering a quarry or pit (except in a district quite new to us), we should probably have in our mind a general idea of what we are going to see, either from former experience of the rocks in the neighbourhood, or from what might otherwise be reasonably expected. We should also infer from the pit itself in what kind of material it had been made—for instance, a brick-yard would be in clay or loam of some kind; a limekiln in limestone, whether of compact nature as those of the 'Lias,' or earthy as the 'Chalk.' In a glance round the excavation we should get still further ideas of the general character and lie of the beds, and then proceed to make a more detailed examination.

Railway cuttings are often found to afford excellent opportunities for observing the strata; although perhaps not of great depth, their length may be sufficient to bring on, one after another, several beds that are even but slightly out of level, and to show them in their actual superposition. As before remarked, junction-sections

are not frequently met with; still, by the dip and general run of the beds, considered in relation to surface features, we are always able to decide (except in case of Drifts, and similar deposits) which is the upper, and which is the lower, of two beds or formations.

Vertical Sections.—The details of coal-shafts, wells, or borings, when drawn to scale, coloured or shaded according to the nature of the rocks passed through, and with all the beds assigned to their proper formations, as in fig. 25, p. 106, constitute what is called a 'Vertical Section.' A great number of vertical sections are issued by the Geological Survey, and are of special value, having been drawn from actual measurements and observation. The official 'Index to the Colours and Signs' employed by the Survey, may be considered as one large vertical section, which shows at a glance the position and average thickness of all British rocks, with the colours and symbols by which they are distinguished.

Notes.—The points of which special notes have to be made, when observing actual sections, are, the kind of rock of which the bed, or series of beds, consists; the number, thickness, and sequence of those beds; their apparent dip and its bearing; also the true dip if it can be at once obtained. All peculiarities must be sought out and noted, such as unconformity, false-bedding, cleavage, concretions, signs of fracture, contortions, slickensides, and so on—the planes of bedding and jointing should be observed, and, in short, anything and everything that can be detected, must be observed and described.

The modes of determining the nature of the rocks, and the groups to which they belong, will be given in Part III., and of searching for, collecting and preserving

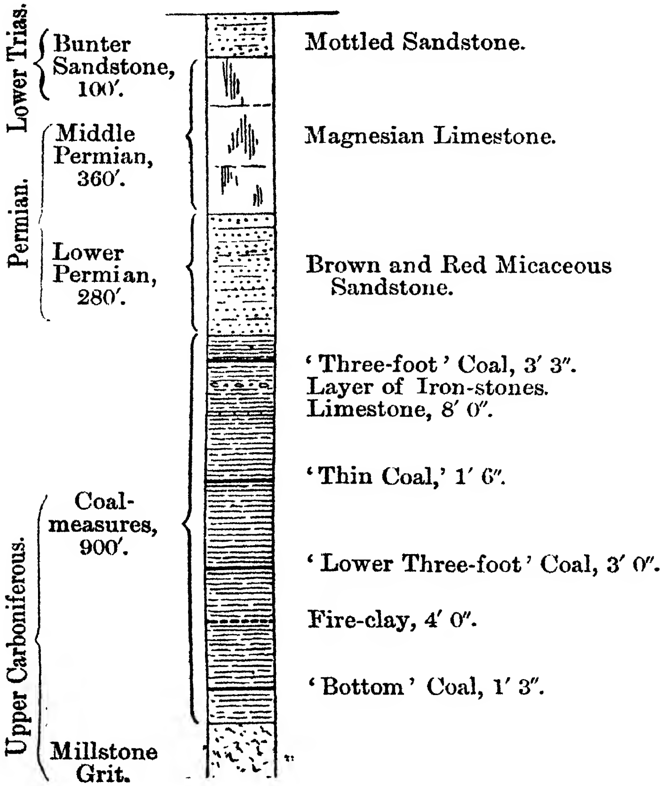

Fig. 25.—Vertical Section.

their included organic remains in Part IV. The methods employed in ascertaining their mutual relations have been already described, but the necessity cannot be too often or too strongly insisted on, of finding out all faults and unconformities, and of noting their influence upon the rocks where seen in section.

The late Mr. J. B. Jukes has justly said* that the practical importance of apparently quite theoretical discussions admit of very apt illustrations. For instance, productive coal measures may have been met with beneath a certain bed, or series of beds, which are really not conformable to them. A person not understanding the fact of the unconformability of the two formations might, after getting the newer beds at another spot, in the direction of the rise of the coal, sink down for it, feeling certain of reaching it at no great depth; whereas, instead of finding coal, the pit would be sunk beyond its outcrop altogether.

Notes of Actual Sections.—As illustrations of the manner in which actual sections are observed and noted, those may be selected that occur in the areas supposed to have been surveyed, and which are represented in figures 5, 6, 7, 8, 12, and 13. (The methods of taking the amount and direction of the dip of the beds are described in the preceding chapter, but those for the determination of their lithological and palæontological characters will be given in the sequel).

(*a.*) In the first slip, figure 5, we came, soon after starting, upon an old pit, nearly overgrown, but in which, at the lowest part, we found, after removal of

* Mems.: Geological Survey, Vol. i., Part II., p. 252.

the fallen soil, a fair section of fine light sand, with many dark green grains scattered amongst its other component particles. Some lines of bedding can just be made out, and these appear to be horizontal, or nearly so, but are not defined sufficiently for a dip to be taken from them, and in one place occurs a thin broken-up seam of harder sand, compacted almost to a sandstone. Some round or pear-shaped lumps of whitish material are imbedded in the harder sand, and which, on being broken across, present a sponge-like texture. These evidently are fossil organisms of some kind, and are transferred to the fossil-bag for future determination.

The top part of the south side of the pit is in soft marly chalk, and as we dig down the slope, this gets darker in colour, owing, it would seem, to the increasing number of the dark green grains; it puts on also a more sandy character. The lowest part of this marly sand, into which the soft grey chalk has passed by gradual transition, contains numerous rounded and cylindrical nodules of a dark brown colour. Shells, and other fossils are tolerably abundant in this layer, some filled with, others enclosed in, similar material to that of which the nodules are composed. The fact is worthy of note, as indicating a chemical or concretionary origin for the mineral, whatever it might be, and we select a few of the nodules for the purpose of ascertaining its nature by experiment; the large number of them, in so thin a layer, is also a point worthy of investigation.

Below the nodule layer we come down to the grey sand with green grains, but without having detected any sudden change where the one rock rests upon the

other. There are no evidences of erosion or unconformity, but there is a rapid change from chalk to sand, representing either an equally rapid change in the conditions of deposit, or (as is more likely), the lapse of a considerable period of time, during which the nodule bed was slowly accumulated. This passage-bed represents the junction, and the line is therefore drawn through that part of the map where the pit is situated. These observations may be entered in the note-book in the following manner:—

Date.................187 .

(Old) Sand-pit ½ furlong N. of ——— church.

Chalk-marl.	*e.* Chalk-marl with green grains (at the south side only) - -	5 feet.
	d. Nodule bed - - - - -	½ "
Upper Green-sand	*c.* Soft light-coloured sand with green grains - - - -	6 "
	b. Layer of sandstone, apparently horizontal - - - -	1 "
	a. Sand, as bed *c.* (with ? sponges) -	2 "

Fossils. (Species determined in Part IV., chap. ii.) *Belemnites*, from the Chalk-marl; many fossils from the nodule bed; *Pecten*, *etc.*, in the sandstone.

(*b.*) The brick-yard beyond the stream (fig. 5) was found to be situated on a clay; this on examination proved to be Gault. It is a tenacious clay, and, as it effervesces slightly upon application of the dilute acid, is somewhat calcareous. It is dark-blue in colour where freshly cut, but weathers to a light grey on exposure. No traces of bedding are visible, unless a thin horizontal layer of grey rounded nodules which occurs in one part, and is tolerably persistent throughout the pit, affords such indication.

Date.................187 .
Brick-yard ½ mile N. of ——— church.

Gault	Dark blue, tenacious, and calcareous clay (weathers grey), ? horizontal — about 7 feet from bottom a layer of phosphatic nodules, shells, and casts - - - 17 feet.

FOSSILS (Species, Part IV. chap. ii.)
Ammonites, Hamites, Belemnites, Solarium, Avicula, etc., etc.

(*c*.) Date.................187 .
New Well ½ mile S.E. of ——— church.
(Information obtained from the well-sinker.)

Gault.	Dark blue Gault, with some seams of nodules - - -	107 feet.
	Hard bed - - - -	1 ,,
Lower Green-sand	Running sand - - -	2 ,,
	Dug 50 feet, bored 60 feet =	110

Water stands 40 feet from surface.

(*d*.) The pit at the back of the farm in the second slip, A^2, gives a good section of some of the harder beds in the Chalk, from the lower part of which they are quarried in large blocks for building purposes. This chalk is harder and denser than usual, it rings beneath the hammer, has a gritty feel and grey or slightly yellowish tinge; it contains many fossils, and a few small brown nodules. The workmen state that a few feet below the lowest bed worked, the chalk is soft and wet; unfit for lime or building. The upper beds seen in this pit are ordinary white chalk, and of a rubbly character.

Date.................187 .
Chalk-pit by ——— farm.

Lower Chalk. *Totternhoe Stone.*	Rubbly white chalk - -	10 feet.
	Hard, thick-bedded, grey chalk, sandy, and with many fossils, and some brown nodules -	15 „
Chalk-marl	Soft marly chalk - - -	—

Dipping slightly S. or S.E.
Fossils (Part IV., chap. ii.)

(*e.*) The clay in this brick-pit is different from that in the first slip (note *b.*), in being much more sandy, in fact, a loam or brick-earth rather than a clay, and of a different colour. The pit extends nearly to the alluvium, where it is 10 feet deep, towards the hill it is 4 feet only, the loam throughout being excavated down to the underlying Gault. The loam is laminated, the bedding being horizontal, and it encloses, here and there, some small white shells, which are, however, to be detected only by diligent search.

Date ....187 .
Brickyard W. of Road from ——— to ——— .

Post-Glacial.	Brown laminated loam, sandy below, with shells, *Succinea*, *Pupa*, etc., at the deepest part of the pit - -	10 feet.
Gault clay.		

(*f.*) Date.................187 .
Gravel pits E. of road from ——— to ——— .
Ferruginous, subangular fine flint gravel, with thin beds of yellow sand, and patches of loam containing shells - - - - - - - - - - 7 feet.
The gravel is coarser below, and in its lower part, large bones have been found.

(*g.*) The following section is interesting as exposing the actual line of division between the Upper and Lower

from the face of the pit, and their thickness can be readily ascertained.

The next proceeding is to select a suitable part of one of the flint layers (in this case on the east side of the pit), to place our hammer-handle thereon in the same line, and on this again the clinometer—the angle of dip reads 7°, somewhere in a south direction. Then we try to get another observation at right angles, or nearly so, to the first—at the north end without success, but on the south we are enabled to do so by removing some fallen rubbish. This reads 0°, consequently the first observation has given us the true dip of the beds, and the east side of the pit happens to have been cut in its direction. We take this by compass-bearing, it proves to be S. 7° E., and we draw on the map, and near the position of the pit, an arrow pointing S. 7° E., with the number of degrees of dip also shown (p. 45).

We observe that the chalk is jointed in every direction, and that the surfaces of some of the joints, diagonal and vertical, are of a dirty yellow colour, and covered with small striæ, as though one face of the jointed rock had slipped over the opposing face, both getting smoothed and striated in the process. This is what has happened, the resulting appearance being known as 'slickenside'—the chalk has been at some period subjected to slight disturbance, a fact which is further evidenced by the small fractures and faults. One of the latter is plainly shown on a small scale in the south-east corner, the downthrow not exceeding a foot—the continuity of the lines of flint being broken, all the layers abruptly rising to that extent.

All the flints are black, but have a thin white coating;

the majority occur in nodules varying in size, from that of a hen's egg to a quartern loaf, but one seam is tabular, that is, it consists of an almost continuous stratum of flint about 1½ inches in thickness. Similar flint in tabular form is occasionally seen running from this seam down the diagonal or vertical joints, and sometimes even cutting directly across a layer of flint nodules.

Date.................187 .

(*k.*) Brick-yard and Lime-kiln ¾ mile S. of junction of—— road with the Roman way.

Loam, mottled yellow, red and brown (similar to that seen in road cutting about 2 miles E.) with intercalated patches of white and yellow sand; passing down into	13 feet
Dark brown very tenacious Clay, which encloses many angular and rolled flints with green-coating	1 „
Chalk with flints, in layers about 6 feet apart, having an uneven and piped surface, and dipping 7° to S. 7° E. - - - - - - - -	30 „

The Chalk is slightly faulted. One layer of flint near the bottom is tabular, and runs off into the joints, which are marked with 'slickenside.'

Grey sand occurs just south of this pit (p. 40) and overlies the loam.

Fossils (from the mottled loam). *Ostrea, Cyrena, etc.*
(from the Chalk). *Micraster, Spondylus, Cidaris, Terebratula, etc., etc.*

Date.................187 .

(*l.*) Old Pit, by west corner of————Wood.

Some hard yellowish beds, with marly layers between, and few fossils except *Ostrea,* which are abundant.

These hard beds may possibly separate the lower from the middle portion of the Lower Chalk.

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Some hard yellowish beds, with marly layers between, and few fossils except *Ostrea,* which are abundant.

These hard beds may possibly separate the lower from the middle portion of the Lower Chalk.

The preceding notes relate to the Cretaceous area supposed to have been mapped as described in Part I., chapter ii., pp. 27—41; those which follow, to the palæozoic area, in chapter iv., pp. 73—84.

(*m.*) Date.................187 .

Railway Cutting W. of ———

Surface soil and drift gravel several feet.

Upper Silurian (*Wenlock Limestone.*)	Flaggy calcareous beds. Limestones, bedded, with calcareous nodules Flaggy beds, as above. Clunch and Shale.	about 12 feet

Dipping W. by N. 5°.

FOSSILS (Part IV., chap. ii.) *Trilobites, Pentamerus, etc.*

Date.................187

-Colliery.

(From a Section in the Manager's Office.)

Various Coal Measures—shales, coals, ironstones, fire-clays, etc.—not outcropping in the area, the first coal in the following section being beyond question that which was first traced W. of the quarry in dolerite - - - - - - - - - - — feet

Coal Measures.	Coal -	2·0	'Fire clay Coal'	4′·0″
	Fire-clay	·6		
	Coal -	1·6		
	Fire-clay - - - - - -			1·6
	Clunch, binds, rock and ironstone			43·0
	Coal -	2·0	'Bottom Coal'	7·0
	Batt -	3·0		
	Coal -	2·0		
	Various Coal-measures, ironstone, fire-clay, etc. - - -			146·0
Silurian	Binds and partings - - -			117·0
	Binds with thin limestones - -			97·0
	'Thin' or 'Little Limestone'	12·0		164·0
	Shales with Limestones	118·0		
	'Thick Limestone' -	- 34·0		
	Shales, etc. - - - - - -			18·0

(*o*.) Date..................187 .
Pit N. of The Skip.

Woolhope Limestone.	Shales, with calcareous concretions. Impure limestone, fossiliferous.

Dipping W. 35°.

(*p*.) Date..............187 .
Limeworks N.W. of ——— Inn.

Shaly limestones - - - - - - - 12 to 14 feet
passing down into
Thick bedded limestone.

Dipping W. 8° (dip taken on the floor of quarry where beds have been removed).

Fossils abundant, (in the shales) Brachiopoda, etc., (in the thick limestone) Corals.

(*q*.) Date..............187 .
Old stone quarry S. of ——— Inn.

In sandstone, white in some places, in others pale yellow, brown and ferruginous.

Fossiliferous in some parts of the section, which is nearly overgrown.

Ideal Sections.—A geological map shows the rocky structure of a district only at the surface, and indeed cannot be supposed to indicate, otherwise than indirectly, what occurs beneath. To the educated eye, however, a good geological map conveys more than a superficial knowledge of the rocks pourtrayed; it demonstrates as clearly as would an open section, although it may be approximately, the relative thicknesses of the formations, and, as plainly as possible, their mutual relations. And when the shape of the ground is known to the observer, or has been indicated to him by a glance

at the chief lines of drainage within the area, it is almost impossible to look at the map and imagine the rocks in any other than in their true position. Still it is frequently necessary, in order that the dip, thickness, and exact relations of certain rocks may be determined, to have ideal sections, based upon certain actual data, which taken in connection with others, known or for the moment assumed, may yield the required results.

It may be observed that these sections are ideal only so far as their details beneath the surface may in one sense be considered uncertain, for the nature of the beds will have been ascertained at the surface, in many cases their dip also, and in others their underground extension will have been shown in accordance with, or will have been checked by, details derived from some well, or boring, upon or near to the line of section. This line will be selected to run over well-known or typical parts of the area, and as nearly as may be at right angles to the strike of the beds, its bearing occasionally changing where necessary in order that these objects may be attained.

Filling in Geology.—It is necessary in the construction of these ideal sections to show all the inequalities of the ground, correctly both as regards distance and elevation, or serious error in the geology will follow as a matter of course. The surveying and levelling required for this purpose are briefly explained hereafter; for the present it may be assumed that a line of levelling has been run and plotted across the area, selected as an illustration of geological mapping. Frontispiece and figs. 5, 6, 7 and 8, chap. ii., Part I.

The geological details are filled in to the section by

the aid of the boundary lines on the map, of the dip and particulars observed in exposed sections or ascertained from wells or borings, and to a great extent by inference from such evidence. The lines of boundary and outcrop are either scaled off from the map, or their position will have been noted in the measurements along the line of section when being levelled. The beds must be drawn with the inclination they would exhibit, true or apparent dip as the case may be, along the actual section line and with all known faults, flexures, and contortions, dotted lines only being used where the details are uncertain. In this operation the table given at page 88 will be found of service, but care must be taken to allow for unevenness of the ground, by drawing a horizontal line to work from through the point at which the calculations are to be applied.

Apparent Dip.—Frequently the line of section will not run in the direction of the dip; in such cases the inclination of the beds must be shown as it would appear in a section cut through them along that line. The difference can be found by calculation, but is more readily ascertained when the dip is 10° or upwards, by reference to the table constructed and published by the late Mr. J. B. Jukes,* and reproduced in the following page.—It is found also, in an abridged form, in the Appendix to his 'Manual of Geology,' with the addition of some valuable hints on the construction of geological sections.

* Mems.: Geological Survey, Vol. I., Part II., p. 334.

Angle between the direction of the Dip and that of the Section.	Angle of the Dip.																
	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	89°
10°	9° 51'	14° 47'	19° 43'	24° 48'	29° 37'	34° 36'	39° 34'	44° 34'	49° 34'	54° 35'	59° 37'	64° 40'	69° 43'	74° 47'	79° 51'	84° 56'	88° 59'
15°	9° 40'	14° 31'	19° 23'	24° 15'	29° 9'	34° 4'	39° 2'	44° 1'	49° 1'	54° 4'	59° 8'	64° 14'	69° 21'	74° 30'	79° 39'	84° 50'	88° 58'
20°	9° 24'	14° 8'	18° 53'	23° 39'	28° 29'	33° 21'	38° 15'	43° 13'	48° 14'	53° 19'	58° 26'	63° 36'	68° 49'	74° 5'	79° 22'	84° 41'	88° 56'
25°	9° 5'	13° 39'	18° 15'	22° 55'	27° 37'	32° 24'	37° 15'	42° 11'	47° 12'	52° 18'	57° 30'	62° 46'	68° 7'	73° 32'	78° 59'	84° 29'	88° 54'
30°	8° 41'	13° 4'	17° 30'	22° 0'	26° 34'	31° 14'	36° 0'	40° 54'	45° 54'	51° 3'	56° 19	61° 42'	67° 12	72° 48'	78° 29	84° 14'	88° 51'
35°	8° 13'	12° 23'	16° 36'	20° 54'	25° 18'	29° 50'	34° 30'	39° 19'	44° 19'	49° 29'	54° 49	60° 21'	66° 3'	71° 53'	77° 51'	83° 54'	88° 47'
40°	7° 41'	11° 36'	15° 35'	19° 39'	23° 51'	28° 12'	32° 44'	37° 27'	42° 23'	47° 35'	53° 0'	58° 40'	64° 35'	70° 43'	77° 2'	83° 29'	88° 42'
45°	7° 6'	10° 4'	14° 25'	18° 15'	22° 12'	26° 20'	30° 41'	35° 16'	40° 7'	45° 17'	50° 46'	56° 36'	62° 46'	69° 14'	76° 0'	82° 57'	88° 35'
50°	6° 28'	9° 46'	13° 10'	16° 41'	20° 21'	24° 14'	28° 20'	32° 44'	37° 27'	42° 33'	48° 4'	54° 2'	60° 29'	67° 22'	74° 40'	82° 15'	88° 27'
55°	5° 46'	8° 44'	11° 48'	14° 58'	18° 19'	21° 53'	25° 42'	29° 50'	34° 21'	39° 20'	44° 49	50° 53'	57° 36'	64° 58'	72° 55'	81° 20	88° 15'
60°	5° 2'	7° 38'	10° 19'	13° 7'	16° 6'	19° 18'	22° 45'	26° 33'	30° 47'	35° 32'	40° 54'	46° 59'	53° 57	61° 49'	70° 34'	80° 5'	88° 0'
65°	4° 15'	6° 28'	8° 45'	11° 9'	13° 43'	16° 29'	19° 31'	22° 55'	26° 44'	31° 7'	36° 12'	42° 11'	49° 16	57° 37'	67° 21'	78° 19'	87° 38'
70°	3° 27'	5° 14'	7° 6'	9° 3'	11° 10'	13° 26'	16° 0'	18° 53'	22° 11'	26° 2'	30° 39'	36° 15'	43° 13'	51° 55	62° 43	75° 39'	87° 5'
75°	2° 37'	3° 38'	5° 23'	6° 53'	8° 30'	10° 16'	12° 15'	14° 30'	17° 9'	20° 17'	24° 8'	29° 2'	35° 25'	44° 1'	55° 44'	71° 20'	86° 9'
80°	1° 45'	2° 40'	3° 37'	4° 37'	5° 44'	6° 56'	8° 17'	9° 51'	11° 41'	13° 55'	16° 44	20° 25'	25° 30'	32° 57'	44° 33'	63° 15'	84° 15'
85°	0° 53'	1° 20'	1° 49'	2° 20'	2° 53'	3° 30'	4° 11'	4° 59'	5° 56'	7° 6'	8° 35'	10° 35'	13° 28'	18° 1'	26° 18'	44° 54'	78° 41'
89°	0° 10'	0° 16'	0° 22'	0° 28'	0° 35'	0° 42'	0° 50'	1° 0'	1° 11'	1° 26	1° 44'	2° 9'	2° 45'	3° 44'	5° 39'	11° 17'	44° 59'

In the article previously quoted (p. 133) Mr. Dalton gives a method of finding by diagram the apparent inclination in a direction oblique to that of the true dip.

'*Problem.*—To find the apparent angle in any required section, from the full dip and deviation of its direction from that of the section (fig. 26).

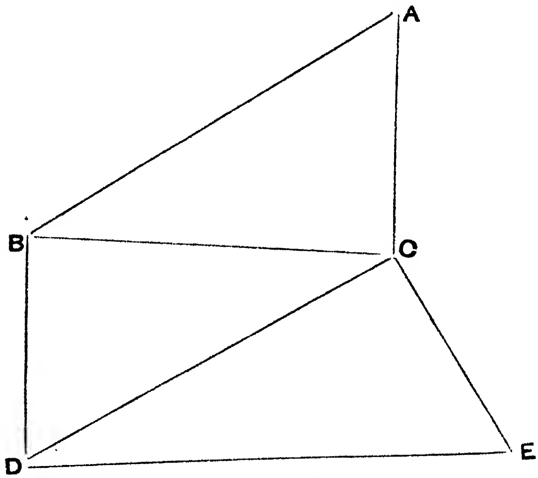


Fig. 26.

'Construct the right-angled triangle A B C, with A B C equal to the full dip; also the right-angled triangle B C D with B C D equal to the deviation; lastly the right-angled triangle C D E, in which C E is equal to A C.

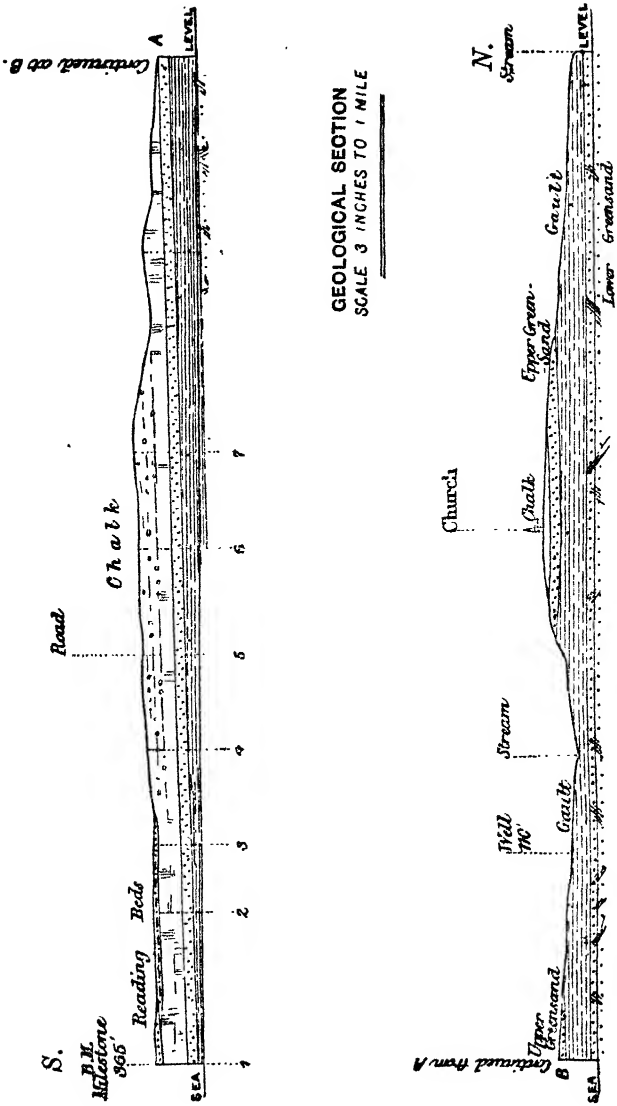
'Then C D E is the required apparent angle.

'*Proof.*—If A B C be a vertical plane along the full dip, and C D E the vertical plane of section, B C D will be a horizontal plane, and A C, C E will coincide, so that B D, A E will be the plane of stratification, giving the apparent angle C D E along the section.'

Downthrow.—In filling in sections, all faults must be shown with the beds on either side of them in their proper place as nearly as it can be determined. The position of a line of fault being known, and the dip of the beds on both sides observed, or worked out, the rocks are drawn with their broken ends abutting against each other, nearly beneath the surface line of the fault. Some inclination is given to the fault itself, the slope, or 'hade,' being to the side thrown down; and allowance must of course be made in the dip, if its direction be oblique to the line of the section.

The amount of downthrow at any part of a fault can be readily arrived at from the known dip, and the lateral shift of the beds. For example:—a bed has been shifted by dislocation 200 yards, at a point where the shifted portion is found to be dipping towards the fault at an angle of 8°. By the table on p. 88 we see that a bed with a dip of 8° gets down 14·5 yards in 100; therefore in 200 yards it will be found at a depth of 29 yards, or 87 feet, which is the amount of downthrow at that particular point. (See also an exhaustive Chapter on Faults or Dislocations, pp. 198-218, 'Student's Manual of Geology,' Jukes and Geikie, 1872.)

Example.—In the section, fig. 27, illustrating the geological structure of the area surveyed, the boundary lines of the Chalk and Upper Green-sand would be scaled from the map, or their position would have been ascertained while chaining as the heights were taken by aneroid, level or theodolite. The north and south boundaries of each, so far as the outlier is concerned, would be united by straight lines, or the actual lines of division would perhaps be more accurately re-



GEOLOGICAL SECTION
SCALE 3 INCHES TO 1 MILE
S.
B.M. Milestone 366'
Reading Beds
Chalk
Road
A
Continued at B.
LEVEL
SEA
1
2
3
4
5
6
7
N.
Stream
Gault
Lower Greensand
Upper Green-Sand
Chalk
Church
Stream
Gault
Well 110'
Upper Greensand
B
Continued from A

Fig. 27.

presented with a slight depression in the centre. For the preservation of the beds as an outlier is doubtless due to their occurrence at that point in a synclinal position, which, as we have seen, presents a barrier to denudation. Dotted lines across the valley between the main mass and the outlier, passing through boundaries, give the inclination at which the beds again begin to dip beneath the surface. Further south the Chalk is shown dipping at an angle of 2° 30′; the true dip is 3°, but the section line is not coincident with its direction, the deviation being 28°; the apparent dip, 2° 30′, is therefore found either by table, diagram, or calculation. The thickness of the Gault at the well being known as 108 feet, the base of that deposit, and the top of the Lower Green-sand beneath can be accurately shown there; the line may be prolonged parallel to the base of the Chalk, but it is provisional only until the section shall have been extended northwards to the boundary of the formation.

CHAPTER III.

LEVELLING.

Surface Profile — Datum-level — Bench-marks — Levelling, *by Aneroid, by Level* — Level-book — Plotting, *from heights*— Levelling, *by Theodolite*—Level-book—Plotting, *from angles*— Instruments.

Surface Profile.—In constructing a geological section it is necessary to have the surface of the ground along the line of such section accurately represented; for if not, error is sure to creep in, where perhaps least expected, as might easily happen in such an instance as the following. A road runs along the line of a proposed section—at one part A, a pit by the roadside exposes a limestone a foot thick, with shale above and below; this bed is found by the clinometer to be perfectly horizontal. The road appears to the eye to be horizontal also, but in reality it rises at a slight angle, say, half a degree. A mile further on another pit, similar to the first, shows a limestone a foot thick, with shales above and below, just the same as at A, also horizontal. The beds seen in the two pits are identical, at least it seems natural to come to that conclusion; whereas, owing to the slight rise, the bed seen at A is at B actually from 40 to 50 feet beneath the surface. It might even happen that the uppermost of two beds would be shown passing

under the lower were the surface to be judged merely by the eye; therefore, if error is to be avoided, the section must be drawn from previously-ascertained data or by the aid of some instrument.

There are many means by which a line can be drawn to represent the surface through any number of given points—by some of them approximately and in a sketchy manner, by others every detail is shown with the greatest accuracy. Among the former are the methods employed in drawing section lines from the published 'heights above the sea,' from contour maps, from heights taken by aneroid barometer, or slopes taken by Abney's level; among the latter, from levels ascertained by the Y—the dumpy—or any other level, and from a series of vertical angles observed by means of the theodolite. All proceed on the same principle of ascertaining the heights at various points, near to or distant from each other, according to the degree of accuracy required, and sketching in the line between those points to correspond as nearly as may be with the surface form of the ground. A few brief remarks follow upon the use of the level and theodolite, as employed for geological purposes. Before the levels for a geological section are run, the beds will generally have been mapped, and the line should be laid out as nearly as can be conveniently arranged at right angles to their strike. For approximate levelling the distances apart of the points where heights are taken can be scaled from the map; for accurate work, measurements by chain are required.

Datum-level.—Whatever means are adopted for taking the heights or levels for a section, it is essential

to decide upon a fixed or standard level from which to commence, and to which reference can be made at any time, and in relation to which all the other heights are calculated. It is usual, as it is most convenient, to refer all heights to the standard, or as it is called the 'datum-level' adopted for this country, that is, the 'level of the sea.' By this term is understood the level of mean tide at Liverpool, a datum from which all the heights marked on the ordnance maps have been calculated. But in some instances it is found more convenient to work from an imaginary horizontal line, or datum, so many feet above or below this standard; in others to select a fixed point on some permanent structure, such as a church or a bridge, and to treat this, or some definite point above or below it, as a datum-level. In geological sections, which frequently show the strata to a great depth, it is usual, as in those published by the Government Survey, to assume a datum, '1000 feet below the level of the sea.'

Bench-marks.—Here and there along, or near to a line of section, a series of intermediate points are selected as 'bench-marks,' for the sake of more convenient local reference at any future time. The heights of these points above or below datum are known from the ordnance levelling, from our own observations, or otherwise, and their positions are indicated or described. All the points on the ordnance maps, where heights are figured, are so many bench-marks, the levels of each having been carefully ascertained, and the result checked by repetition and calculation.

It is not always necessary, nor is it always possible, to obtain a bench-mark of known height above the sea, from which to commence a proposed line of geological section; in such cases a local starting-point must be selected. If near home, as good a bench-mark as any is the step of one's own front door, and for aneroid observations, which are frequently taken for other purposes than a continuous section, none could be better. Whilst running a section line, started from a local bench-mark, we may possibly come across one of the published ordnance heights, its position being indicated by a 'broad arrow,' ↑ cut in the wall or post where the level was taken. The horizontal bar of the arrow is exactly at the level selected, the height of which, thus ascertained, will enable us to reduce our results to 'sea-level,' even from the commencement.

Levelling.

By Aneroid Barometer.—The possibility of taking heights by this instrument is based on the fact of the weight, or pressure of the atmosphere, varying as the height above the level of the sea. This pressure is everywhere subject to almost constant change, at the same place, and at the same height, owing to alterations in the atmospheric conditions of wind, moisture, and so on. Therefore some means must be adopted, when levelling by the aneroid, to compensate for any such change that may occur during the time of making the observations, and by which cause, in addition to the difference of height, the indicator would be deflected.

The circumference of an aneroid barometer is graduated to inches and hundredths of an inch, and on this scale

the needle indicates the varying height of a column of mercury, that would be sustained, or counter-balanced by the changing weight of the atmosphere. Sometimes it has also a movable outer circumference, divided into parts, about 900 of which correspond with 1 inch on the pressure scale; because a column of air, about 900 feet high, is equal in weight to a column of mercury, of the same diameter and 1 inch in height. Therefore, as the mercury sustained in an ordinary barometer would fall 1 inch for every 900 feet to which it might be raised higher, or rise for every 900 feet lower, the needle of an aneroid gives equivalent indications on this outer circumference, thus saving the labour of calculation.

Some instruments have no outer circumference, the inner one then being divided on a graduated, instead of a fixed, scale for the indication of heights; the graduation is necessary because a given rise or fall exerts a varying influence under different degrees of atmospheric pressure. These aneroids have an outer ring carrying a pointer which is set opposite to the needle at starting; this kind of instrument is to be preferred for its greater accuracy.

In levelling by aneroid, the pointer, or the zero point of the circumference, must be brought round to a position exactly opposite the needle, the observer standing at the time on the selected bench-mark; the instrument should however have been previously carried in the pocket or in its case for a few minutes, so that any difference of temperature may have its effect before and not after this adjustment.

Upon arrival at each point where an observation is intended to be made, as the summit of a hill, the bottom

of a valley, the site of an exposed section, and so on, note is made of the variation of the needle-point—as a rise or fall of pressure in inches or hundredths, if the instrument is graduated for pressure only; as so many feet higher or lower, if divided also for elevation. The indicator is not to be shifted at each station, but the height of every one taken as so much above or below the bench-mark chosen for a starting-point. As stated before, these heights will not be correct if the atmospheric pressure has changed in the meantime. Some plan is therefore essential for the elimination of errors arising from this cause. Three methods are given below; *a* and *b*, being of the simpler kind, will yield fair results; *c* must be adopted where greater accuracy is required.

(*a.*) If the observer can return home along the route by which he came out, and has the time at command for making a second series of observations at the same points, the error arising from atmospheric change may be to a great extent eliminated. The indicator must remain in the same position as at starting, and the heights be again taken in reference to the primary bench-mark. For example, suppose five points on a line, at which the two series of observations are as follows:

	B.M. Finsbury Park Gate.	1st ⊙ (station) High ground in park.	2nd ⊙ Midland Railway Bridge.	3rd ⊙ Summit of Mount Pleasant.	4th ⊙ Bridge over stream near Hornsey.
1st series	840	908	893	985	
2nd series	864	926	905	991	
Difference	24				

The barometer has evidently fallen, during the time

of taking the observations through a space equal to 24 feet, making the bench-mark appear to be 24 feet higher than at starting, and, as a matter of course, all the other stations too high also in due proportion. We assume that this fall was gradual and equally distributed over every portion of the two journeys; therefore half the amount, *i.e.* 12 feet, must be deducted from the mean of the two observations at each place; the result is the required elevation.

	B.M.	1st ⊙	2nd ⊙	3rd ⊙	4th ⊙
	840 864	908 926	893 905	985 991	856
	½/1704	1834	1798	1976	
Mean	852	917	899	988	856
Deduct error	12	12	12	12	12
	840	905	887	976	844
Deduct reading at B.M.	840	840	840	840	840
Height above B.M.	0	65	47	136	4

When an instrument is used having the divided movable circumference the zero point is set opposite the needle at starting; the sign + is then prefixed to any reading above the B.M., for which the barometer will have fallen, or receded to the left hand; the sign — to any that may be below as indicated by a rise or movement to the right when facing the instrument.

(*b*.) A somewhat similar method is to note the time of starting, and of making each observation; then on again reaching the home bench-mark, without having

gone more than once to each intermediate station, to again observe the time and the rise or fall of the barometer. This rise or fall must be distributed, in proportion to the time that elapsed before each was taken, over the station heights, as additions to or deductions from the registered elevation.

The time occupied in taking the above observations, that is to say, in travelling from Finsbury Park to Hornsey and back, was one hour, during which the barometer had fallen a distance equivalent to 24 feet, or to 12 feet during the outward journey of half an hour, assuming the fall to have been constant and regular. This amount must be proportionately divided between the stations; supposing them to be equidistant, one-fourth, or 3 feet, to be deducted from the first reading beyond the bench-mark, 6 feet from the second, and so on.

	B.M.	1st. ⊙	2nd ⊙	3rd ⊙	4th ⊙
	840	908	893	985	856
Deduct error		3	6	9	12
		905	887	976	844
Deduct the reading at B.M.	840	840	840	840	840
Height above B.M.	0	65	47	136	4

It will be seen that the foregoing methods *a* and *b* are founded upon the assumption, that the atmospheric rise or fall of the barometer has been consistent throughout the time occupied in making the observations; but this probably has not been the case, for the pressure may be increasing at one part of the day, and be steady

or even falling at another. The following method (*c*) is free from this source of error, and the accuracy of its results depends solely on the perfection of the instruments employed.

(*c*.) An assistant and two aneroids are required by this method, the instruments being of sufficient accuracy for no perceptible difference between their indications to arise under varying pressure. The readings are taken at each station by one instrument, and at some definite time, such as at the hour, half-hour, or quarter; and the assistant, at home, or wherever the starting-point may have been, observes and records the reading of the second instrument at the same intervals. The two sets of observations are afterwards compared, and the difference of reading gives the height of each station, above or below the bench-mark, without regard to variation in the pressure of the atmosphere.

By Level.—The principle on which all Levels are constructed is that of a perfectly horizontal visual line intersecting a graduated vertical staff, the difference of readings corresponding to the difference in level of the station where the staff has been placed. If the height of one of these be known, that of any other is readily ascertained in relation to it, by the difference in their readings. The heights of any number of places may be thus determined, the level taken at each of them being 'reduced,' by addition or subtraction, to its height above or below the bench-mark, and the height of this being known, the levels can be reduced to their value in regard to 'datum-level.'

The Level consists of a telescope, having a fine cross-wire placed horizontally in its line of sight, with a

spirit-level fixed on it parallel to its axis, by means of which and three (or four) plate screws, it can be adjusted so as to be perfectly horizontal in whatever direction it may be turned. The line of sight thus represents a horizontal plane, and the cross-wire must necessarily, within certain limits, be seen by the leveller to intersect distant objects in the same plane with itself. The instrument is supported on three legs, from which it can be removed for convenience of carriage. The observations are taken upon a staff placed at all the stations in turn; this staff is capable of being extended to 14 feet in height, and has one side divided into feet and hundredths. It is seen inverted through the Level with the ordinary eye-piece, but the eye soon gets accustomed to reading it in this position; and the point of the staff cut by the cross-wire can be accurately read off, being magnified by the telescope.

The distance apart of the various stations can be either measured by a chain, or scaled from the map on which the line of section has been laid down—the correctness of the height at each station is not affected by want of accuracy in this respect, as it is when taken by the theodolite. The instrument should always be placed about mid-way between the two places at which back- and fore-sights are being taken, so as to minimise the slight error arising from 'curvature' and 'refraction.'

In running a set of levels by this instrument, and scaling the distances of definite points from the map, (the intervening surface line being sketched in by eye and hand), it is immaterial whether the intermediate levels be taken directly along the line, or by a more

convenient route, so long as each of these points be made a station for an observation.

As an example of levelling by this instrument we may take the line of section running across the area geologically surveyed (Part I.), commencing at a mile-stone in the S.E. corner (fig. 8, p. 38). On this, the 'broad-arrow' has been cut, and it is shown thereby to be an Ordnance bench-mark, the height of which, above the sea, is ascertained to be 365 feet. We may take the distances from the map where our line crosses roads, brooks, and so on, reserving the example of measuring by chain for the theodolite illustration. But as these points are too far apart, and at too great a difference of level for the instrument to be placed once only between each two, we must take intermediate observations.

The bench-mark, that is, the milestone of which the reduced level is known, must be the starting-point, so having drawn on the map our proposed line of section passing by the church, we proceed in the following manner. The instrument is set up on the road a few chains from the bench-mark, and the plate-screws are turned until the spirit-tube indicates in every direction that its position is horizontal. The assistant holds up the staff upon the milestone, so that its base coincides with the upper line of the 'broad-arrow,' and a reading is then taken. This being entered in the level-book, page 137, as a 'back-sight,' in this case, 10·90, a second look must be taken through the telescope for the purpose of checking the accuracy of the first reading. The man then takes the staff on along the road, which runs about in the right direction, to a distance roughly equal to that of the instrument from the milestone. A reading

is taken upon it, 2·10, entered as a 'fore-sight,' and checked by a second reading, when the Level is carried forward some chains beyond the staff, and all the operations are repeated. The staff will have been turned round to face the instrument in its new position, but care must be taken that the back- and fore-sights are read off without any other alteration in its position.

The levelling is carried on in this manner, along the road, just off the actual line, to the cross-ways, when it must be managed for the staff to be placed on the road where it is cut by the section-line, this being one of the points to be scaled from the map. Then the line is followed, or nearly so, in the direction of the cottages, by which it passes down the escarpment (where shorter distances apart will be necessary, owing to the rapid fall) by the well, across the brook, and past the church, to its northern termination.

The accompanying pages of the Level-book will best explain the manner in which details, as far as the first stream, are observed and entered, as they come under notice or require specification. The levelling is continued in the same manner beyond the stream, and over the Chalk outlier also, care being taken to obtain the heights as nearly as possible upon all geological boundaries.

From . . . Milestone, N. 35° W. passing by . . . Church.

Back-sight.	Inter-mediate.	Fore-sight.	Rise.	Fall.	Reduced Level.	Dis-tance	Remarks.
					365·00		B. M. Milestone.
10·90		2·10	8·80				
12·17		1·50	10·67				
13·00		·40	12·60				
12·08		1·00	11·08				
13·10		1·15	11·95				
			55·10		420·10		Boundary of Loam.
9·94		·74	9·20				
14·00		1·00	13·00				
12·50		·40	12·10				
14·60		1·66	12·94				
12·90		1·10	11·80				
12·73		1·73	11·00				
			70·04		490·14		Road.
12·08		·40	11·68				
14·00		·08	13·92				
13·41		1·04	12·37				
12·90		3·11	9·79				
11·17		.78	10·39				
9·87		1·17	8·70				
13·93		·90	13·03				
			79·89		570·03		Top of Chalk Escarpment.
5·03		10·18		5·15			
2·40		12·90		10·50			
1·09		12·87		11·78			
3·18		13·86		10·68			
1·03		12·90		11·87			
1·10		13·10		12·00			
·74		13·75		13·01			
·17		12·81		12·64			
1·00		13·80		12·80			
2·25		13·70		11·45			
				111·88	458·15		Top of Lower Escarpment.

Back-sight.	Inter-mediate.	Fore-sight.	Rise.	Fall.	Reduced Level.	Distance.	Remarks.
					458·15		Top of Lower Escarpment.
2·10		12·14		10·04			
1·73		12·80		11·07			
3·03		13·91		10·88			
1·18		12·76		11·58			
·93		13·01		12·08			
10·08		7·71	2·37				
3·18		11·25		8·07			
1·11		11·71		10·60			
1·00		12·90		11·90			
2·11		13·11		11·00			
·89		13·21		12·32			
1·30		11·40		10·10			
2·00		12·10		10·10			
			2·37	129·74			
				2·37			
				127·37	330·78		Boundary of Chalk.
3·17		12·75		9·58			
1·14		13·80		12·66			
·19		13·10		12·91			
1·02		13·70		12·68			
2·00	10·40			8·40	274·55		Boundary of U. Green-sand.
		11·90		9·90			
3·20		12·90		9·70			
1·80		12·81		11·01			
1·11		13·20		12·09			
5·03		13·41		8·38			
1·08		13·85		12·77			
1·17		12·74		11·57			
·19		13·40		13·21			
3·76	1·08		2·68		197·00		By Well (110 feet deep).
		12·84		9·08			
2·20		10·10		7·90			
3·00		12·84		9·84			
2·17		8·41		6·24			
2·40		13·19		10·79			
				180·31	150·47		Stream.

It will be seen from this example of a level-book that the heights of only certain stations are worked out—those of the others being unnecessary, indeed many of them are off the line. The mode of reduction is to add up the 'rises' and 'falls,' to subtract the smaller sum from the larger—the remainder, according to the predominance of 'rise' or 'fall,' to be added to or deducted from the height of the last station where it was calculated. In making the additions, all 'intermediate' sights are to be disregarded, and the calculations at those places are enclosed between lines to indicate that they are not to be included. The final result may be checked by adding together all the 'back- and fore-sights,' deducting the one amount from the other, as before, the result being subtracted from, or added to, the last height obtained.

Plotting—from reduced levels.—Before considering a different method of taking surface levels, it will be well to see how the results of the preceding and similar observations are plotted; that is, reduced to the form of a representative drawing. The method in all of them is the same, a straight line, to represent the datum-level, being first drawn on the long slip of paper usually employed. Along this line are set off, by scale, the distances of each station in succession; and lines are drawn in pencil at right angles to it through all these points. The 'reduced level' of each station is then scaled off on its vertical line, and another line is sketched in, running through all these reduced levels, and as nearly as may be conforming to the shape of the ground between them. This last operation will be much facilitated, and greater approach to accuracy be secured, by sketch-lines made in the field on the plain side of the level-book.

Sections may be plotted from ordnance bench-marks if they are sufficiently numerous, the proceeding being exactly the same as from our own reduced levels; also from contour maps, all points where the line crosses a contour being treated as stations, the distances of which are scaled off and the heights, in their proper position, inserted.

By Theodolite.—The method of taking levels by the Theodolite differs from that by the Level, in the visual line of the former not being in a horizontal plane, but inclined at various angles to the horizon according to the slope of the ground between the stations. The telescope, cross-wire, and spirit-level are the same, and the Theodolite can be used as a Level if desired, but the telescope is swung to move vertically, and the angle at which its line of sight is made to coincide with any object is indicated on a graduated arc. This is attached to and moves with the telescope, the amount of inclination of the latter being read off the arc with the greatest accuracy by means of a fixed vernier scale.

For levelling by the Theodolite it is necessary that the instrument be placed on the line of section, unless correct heights at definite points only are required; also that correct measurement be made of the distance between it and the places at which observations are taken, for it is evident that an inclined plane gets to a greater or lesser height at every additional unit of distance.

The stations on the line are primarily found by compass-bearing, but this is not necessarily taken every time the instrument is set up. It will frequently happen that an object at a considerable distance is seen to be in the correct line, and by chaining straight

towards such object the desired end may be attained with much less trouble. When, to get the proper line of direction, a bearing has to be taken, the needle beneath the telescope is set free and the instrument is revolved on its horizontal plates until the needle comes to rest at the proper angle—allowance of course being made for magnetic variation.* In this, and in all other manipulations of the Theodolite, the process is commenced by bringing it nearly into the required position and then fixing it by the 'clamping screws,' the operation being completed to the greatest nicety by means of finely-cut 'tangent screws' provided for the purpose. The divisions of the arc, plates, and verniers are so minute that a pocket-lens must be used in reading them.

The measurements are made along the surface, flat or inclined as the case may be, with a chain 22 yards ($=\frac{1}{80}$ of a mile) in length, divided into 100 links. The chain, made with strong wire, has a handle at each end and a brass or other mark every ten links to aid in counting the odd parts of each admeasurement. Ten iron arrows, with pieces of red cloth on each, are carried by the leading chain-man, who puts down one at the front end of every chain measured; when the extent of ten chains is reached the arrows, picked up in passing by the chain-man at the rear-end, are restored to the leader, and a note is made of every such ten chains passed over.

The services of three men, or boys, are required, two for chaining, and the third for assistance in taking the observations. The work can be carried on with two

* *Ante*, pp. 6, 7.

only, but with a third it is done much more expeditiously; the man, who is most to be relied on for care and accuracy, or is accustomed to the work, should be put in the rear of the chain.

As every spot where the instrument is placed will be constituted a 'station,' the height from the ground of the objects on which sights are taken should be about the same as that of itself, *i.e.* 5 feet; the visual line will then be carried from end to end at a uniform distance of 5 feet from the surface. A light staff of that height, with a cross-piece at top painted white, is a good thing to be carried by the assistant and placed by him on each place in turn where the observations are taken—or without this staff the sight may be taken on the assistant himself, as on the top of his head or the line of his eyes.

But the fore- and back-sights at an object must always be taken on it when at the same level; if this be done it does not matter about its being a little too high or a little too low relatively to the surface. For instance, it may sometimes be convenient to place the man, with or without the staff, on the top of a bank or on a gate; this will cause a local error of a few feet, but if both fore- and back-sights be taken on it without alteration in its position a constant error is avoided, which would otherwise be carried on to the end of the section.

If the line of section, across the map (figs. 5 and 8), were run by Theodolite, the proceedings would be somewhat as given below. Assuming that the start be made from the milestone, which is also an ordnance bench-mark, 365 feet, the first thing to be done is to find the line bearing N. 35° W. along which the section

has to be levelled. The instrument is set up and manipulated by the plate-screws until the spirit-levels indicate that it is in a horizontal position. It is then turned round, with the needle free, until the latter comes to rest at 16° 15′ (35° W.—18° 45′ variation= 16° 15′), is then clamped and the final adjustment made by the tangent screws. The telescope is now unclamped to move vertically, and as it points directly along the line of section, any objects seen in the centre of its field are in the line and may be pointed out to the chain-man for his guidance. We may assume that a tree in this instance comes in, and that beyond it the line passes just between two cottages discerned at a long distance. After seeing that the leading man has his ten arrows, and that the chaining has been started in the direction of the tree, we place our assistant at the milestone with the staff on the bench-mark, and walk on to where a rise in the ground begins. In doing so we may observe whether the chain-man is keeping his leader to the line; he should do this by looking along the chain and, by a wave of the hand to either side, getting it ranged properly before the arrow is stuck in the ground. Having set up the instrument and booked the length, ten chains, in the level-book, we send on the chain-men to measure to the next fence. Adjustment for horizontality having been made, we direct the telescope back to the head of the staff on the bench mark, clamp it, and by turning the tangent-screw get the cross-wire exactly to coincide with it. We read off the result as a depression of 0° ·50′, and enter it in its proper column, making a little cross also in the column headed ‘Back,’ to indicate that this is a ‘back-sight,’

take another look through the telescope and at the reading to see that there is no mistake, and beckon the assistant to come on. He is sent forward immediately to stand in the fence to which the chain-men have measured, in such a position that he can be seen both from the instrument and from the ground beyond. Another sight is now taken on the staff and entered, this time as a 'fore-sight,' 1° 5′ elevation, again checked by repetition, and we walk on to find that the measurement from the instrument to the fence was 4 chains 33 links. We enter this, go on again with the chain-men, set up the instrument, take a back-sight, and, in fact, repeat exactly the former operations.

The spots on the line where changes occur in the shape of the ground should be selected as stations for the instrument and for the staff, the smaller features being described or sketched in and noted as we proceed; of this, the copy of the level-book given on p. 145 will afford an illustration.

From......Milestone N. 35° W. passing by......Church.

Station No.	Forward.	Back.	Station No.	Elevation.	Depression.	Distance.	Remarks.
1							B. M. Milestone, 365′.
		x	2		·50	10·00	
3	x			1·5		4·33	
		x	4		6·20	6·33	Slight rise between. Boundary of Loam about midway.
5	x			8·0		6·20	Road.
		x	6		4·0	7·00	
7	x			4·0		6·50	
		x	8	1·30		3·00	Rise between.
9	x				16·30	4·33	
		x	10	·45		5·50	Hollow between.
11	x				5·	1·80	
		x	12	11·10		4·30	
13	x				5·30	4·00	
		x	14	9·0		3·50	Boundary of Chalk.
15	x				9·35	5·50	„ Green-sand.
		x	16	6·28		4·00	
17	x				7·30	4·40	Well, 110′ deep.
		x	18	7·30		6·30	Stream.
19	x			16·30		7·80	Boundary of Green-sand.
		x	20		17·10	3·80	Boundary of Chalk.
21	x			11·5		4·00	. . . By — Church.
		x	22	5·30		7·00	Boundary of Chalk.
23	x				5·55	4·50	
		x	24	20·30		1·30	(Rise between) Boundary of Green-sand.
25	x				8·10	8·00	
		x	26	5·5		7·70	Slight hollow between.
27	x				7·10	3·30	Stream.

Two, or more, forward sights may occasionally be taken with advantage from one station, to get quickly over a deep hollow or ravine, but not more than one back-sight can very well be taken, on account of the difficulty that would arise in their being plotted.

It will sometimes occur that the face of a cliff or quarry, that a sharp or rugged slope, is such that it cannot possibly be measured with the chain. The height must then be ascertained by means of two, or more, observations taken with the Theodolite; one at some distance from the base, and the other nearer to it by a few chains; the length and the fall of the ground

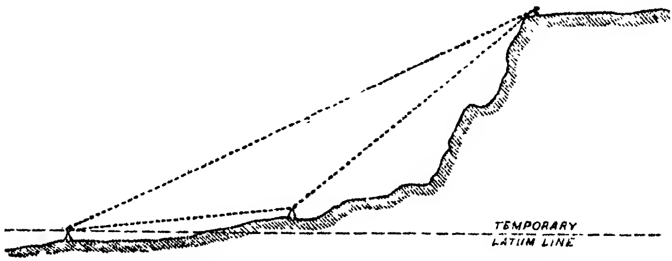


Fig. 28.

between the points must then, of course, be accurately determined. One of the observations can be made from the last station, and the other in advance of it, the sights being taken on the staff or other object upon the summit. These, with the length and fall between the points being plotted as a diagram and with reference to a temporary datum line, will give at the intersection of the angles the height and position of the object relatively to such datum (see fig. 28).

Various expedients may with advantage be occasionally adopted under exceptional circumstances, as, for

instance, in coming to a field of standing corn, which would be injured by the chain-men measuring through it, or a tract of marsh land flooded so as to be impassable. In the former case the exact level of an accessible object on or near the line may be transferred across the field, by clamping the instrument at zero, and noting where the cross-wire cuts some object on the other side; the distance must be judged, or it may perhaps be scaled from the map. In the other supposed case, the staff or man should be placed at a station by the edge of the water on the near side of the marsh, and in a similar position when starting again from the other side; the space between the two points will of course be level, and the distance must be obtained as before.

Sometimes also a great deal of unnecessary labour may be saved by going somewhat off the line, as round a wood or a village, care being taken to note the horizontal as well as the vertical angles at which the line is left and rejoined, also the angles and the distances between all the intermediate stations. These being afterwards laid down show the line actually levelled, and the distance between the points of departure can be scaled off; the ascertained difference in height will require no alteration.

Plotting—from Angles.—The method of plotting levels taken with the Theodolite varies somewhat from that described for those with the Level, and must be performed with great care for the result to be satisfactory. A straight line is drawn on the long strip of paper to represent the 'datum line,' sea-level, or otherwise, and another line perpendicular to it, near the left-hand end of the paper, which should be also the southern

end of the section. On the vertical line, which corresponds to station 1, set off the height above datum of the bench-mark, 365 feet in the case supposed. Then with a protractor, or other instrument, lay down a line inclined upwards from the datum line as many degrees and minutes as are recorded in the first observation. The angle is best laid down, or at all events pricked off, by the datum line, from the point where crossed by the vertical line (on which point the centre of the protractor would be placed), and then transferred by parallel rule to its proper position as starting from the bench-mark. The measured distance is then scaled off along this inclined line, and another vertical line drawn, in pencil, through the measured point and through the datum line. This point is the second station, and a figure 2 is made below it for the convenience of future reference. Another line is now laid down in a similar manner for the 'fore-sight,' (this being an 'elevation' forwards rises in that direction), is measured off, and numbered. The first observation from station 8 is a 'back-sight' and 'elevation,' therefore 'depression' forwards, and will be laid down with a different inclination from those previously drawn.

These straight lines of course do not represent the curved parts of the surface, but give correct heights at the points selected for stations; the line, when inked in between, must sweep naturally through these points, the sketch lines in the level-book supplying the shape of the intervening ground. Where a station is on a road, or by a stream, a pit, and so on, the fact must be recorded on the section; and where the line crosses or passes by such points between the stations, note must

be made of the intermediate measurement to them, so that their position may be correctly indicated. The section, fig. 27, has some lines dotted at the left hand; these represent the working lines which in practice would be drawn in pencil, to be erased when the surface line, with the roads, etc., had been drawn in Indian ink.

It should be borne in mind that drawing-paper shrinks considerably, so that it is advisable when drawing maps, or plotting sections, to lay down and ink in all the scales used in the work, not when finished, but at its commencement.

Abney's level is a very useful little instrument for approximate work, in measuring the angles of slopes, and ascertaining heights, although its construction is not such as to admit of taking observations sufficiently accurate for long sections. It consists of a small tube, having a cross wire and carrying a vertical arc divided into degrees; the angle is taken by intersecting some distant object with the cross wire, at a moment when the body of the level is horizontal, as shown by a spirit-level seen in the tube through the medium of a reflector.

Goodchild's level is also extremely useful for similar purposes, and as a cheap and very convenient pocket instrument can be strongly recommended.

Lebour's calliper scale, in which compasses and scales are cleverly combined, is most useful in drawing maps, plotting sections, or measuring heights and distances. It is divided, on either edge, into the scales of one inch and six inches to a mile (those most in use in geological surveying), and has a sliding centre which carries a metal point, resting against another similar point on the

scale itself, when the reading is at zero. As the slide is drawn out the points (which fold back when not in use) separate, and their distance apart is acurately read off from the scale, one inch to the mile on the one side, six inches on the other; therefore, for these two scales, the instrument supplies the place of a pair of proportional compasses.

At the suggestion of the late Mr. J. B. Jukes, the protractor (fig. 2, p. 12) was prepared, with one-inch and six-inch scales, and with the vacant space utilised by the insertion of portions of the table of dip, depth, and thickness. This combination is valuable where portability is a consideration, and one of these protractors should be found in the note-book or map-case of every field-geologist.

A note-book has been got up at the request of the author, which is specially adapted for field-work. It is made from strong thin paper, plain on one side for sketches, and showing water-mark squares on the other, by aid of which diagrams or sections may at once be drawn with tolerable accuracy from paced or estimated measurements. It is bound limp, with corners rounded off, and has pockets for two pencils, which may be coloured, for filling in sections in contrasting tints, as a black-lead pencil will be carried in the pocket or map-case.

A short list follows of the instruments most generally used in geological surveying, with their prices and the names of those by whom (amongst others) they are supplied. It must not be assumed, however, that all in the list are necessary, or that those which are indispensable are all to be carried at the same time; only those should be taken which are likely to be required during the day, as the geologist, who must get over a good deal of ground when engaged in field-work, cannot well carry too light an equipment.

Instrument.	Referred to on page	Supplied by	Price.
Clinometer - -	(fig.15) 92	Troughton and Simms, Fleet St., London.	18*s*.
Pocket-compass and clinometer, in case	(fig. 1) 9–10	" "	£1 10*s*.
Prismatic compass -	11	" "	£2
Leather sling case for ditto - -		" "	6*s*. 6*d*.
Hammer, geological, of various patterns		" "	From 2*s*. 6*d*. to 5*s*.
Leather belt for ditto - -		" "	5*s*.
Hammer, pick and spud combined (Penning's) -	(fig. 3) 14	" "	10*s*. 6*d*.
Fern trowel, in leather case -	15	" "	7*s*. 6*d*.
Chisels - - -		" "	6*d*. to 1*s*.
Protractor (Jukes's) -	(figs. 2,4) 12, 15	" "	7*s*. 6*d*.
Aneroid barometer, in case - -		" "	From £3 10*s*. to £5 5*s*.
Calliper scale (Lebour's) - -	149	Robson, Newcastle-on-Tyne.	5*s*. 6*d*.
Level (Goodchild's), in case - -	"	" "	3*s*. 6*d*.
Level (Abney's), in case - -	"	Troughton and Simms.	£2
Map-case, 6½″ × 5″, with pocket, and lined with donkey-hide for notes or sketches -	27	J. Smith & Co., 42, Rathbone Place, London.	5*s*. 6*d*.
Note-book, 7″ × 4″ -	150	Marlborough & Co., 51, Old Bailey, London.	5*s*.
Scales, various - -	15	Troughton & Simms.	From 2*s*. to 12*s*.
Pocket-lens, 1, 2 or 3 powers -		" "	From 1*s*. 6*d*. to 3*s*. 6*d*.
Acid bottle - -		" "	From 1*s*. 6*d*. to 2*s*. 6*d*.
Valise, for specimens, etc. -		" "	From 5*s*. to 15*s*.

PART III.

LITHOLOGY.*

CHAPTER I.

ROCKS.

General remarks — Rocks — Veins— Metals — Peculiarities of structure in certain rocks—Concretions—Slickensides.

General remarks.—Every one who has carefully inspected a good collection of rock specimens must have noticed the great numbers there are, both of different kinds of rock and of intermediate varieties. Distinct as they may be in some particular, these varieties are still so nearly alike, that a series may frequently be selected, presenting a perfect gradation between rocks that are quite distinct if studied by themselves, and partaking more or less of the characters of each. For instance, we may have a pure limestone at one end, and an equally pure sandstone at the other, with calcareous sandstones and siliceous limestones between, constituting

* Metals and Minerals, as constituents of Rocks, are, for sake of convenience in the treatment of the subject, included under this heading, Lithology.

a gradual series. In the central specimens of this series it is impossible to say, except from analysis, exactly where the calcareous or siliceous element ceases to predominate, and whether they should be termed calcareous sandstones, or siliceous limestones.

The same proposition holds good as between limestone and clay, sandstone and clay, and between all kinds of sedimentary and organically-formed rocks. Stratified rocks of each kind have been formed during all geological periods, and their constituents must, of necessity, vary according to the differences between those, whether aqueous or igneous, from which they have been wholly or partly derived, and to the relative areas occupied by all or any of those which have directly contributed to their formation. The deposits resulting from denudation differ as the rocks denuded, and are further modified by the sediment from each one being commingled more or less with that derived from those which are dissimilar. Another reason for this gradual divergence is the existence of certain agencies, organic or chemical, in their production, within limited areas only; which agencies do not end abruptly, but gradually die away, influencing less and less the composition of the rock being formed as the distance increases from the centre of their activity.

The metamorphosed stratified rocks present similar gradations, and the eruptive and intrusive rocks vary, within certain limits, according to the geological age during which they were ejected or intruded; their present characteristics are, however, partly due to subsequent metamorphism, and to other causes which are not yet thoroughly understood.

Many rocks possess very definite characteristics, by which not only their class may be distinguished, but by which they may be correctly referred to their geological position as part of such a formation, or even to some particular horizon in that formation. Others are of such a character that it is difficult to decide what is their geological age; it may, indeed, be impossible from lithological character alone, when their included fossils, if any, will furnish additional and valuable evidence. And in consequence of the changes which some rocks have undergone subsequent to their formation, it is not at all times easy to decide even to what class a specimen belongs; it must then be subjected to certain tests for its determination. There are simple tests for application in the field, to ascertain the class of rock that is under examination; and more delicate tests, involving the use of apparatus at home, by which the field results may be checked and extended. In most cases the simple directions given below will go far enough, in others they will not be sufficient, to arrive at an accurate solution. It will be found advisable to consult such works as are devoted to the subject, or to obtain the assistance of a professed mineralogist, for the ultimate determination of a difficult specimen.

In the published works on Petrology and Mineralogy, the plan usually adopted has been to name a rock or a mineral, and then to describe the results obtained by subjecting it to certain processes. But to the geologist, who goes into the field and encounters an unknown rock, this method of determination involves a vast amount of labour and perseverance. The object aimed at in the compilation of the following Tables of Tests for determi-

nation of rocks and minerals (pp. 185—195) has been to save much of this labour by reversing the usual process. The results of several simple tests are tabulated together, and the nature of the rock subjected to experiment is determined from its behaviour under those tests applied in their proper order. This plan must necessarily be confined within certain limits; but a fair approximation to the desired result may be obtained, with indications for more detailed operations. It should be unnecessary to insist upon what all geological text-books so strongly recommend, that an acquaintance with the appearance and characteristics of all ordinary rocks and minerals should be formed by careful study of cabinet specimens.

Mr. F. Rutley, in an important work recently published,* says, 'We may with considerable truth define all rocks as mineral aggregates. The state of aggregation of a rock depends upon the way in which it was formed, and the changes which it may subsequently have undergone. . . . . If we examine a fragment of rock, we find it to consist, as a rule, of crystals, the edges and angles of which may either be sharply defined or rounded, and which are cemented together either by crystalline or amorphous mineral matter; or we may find it composed of large or very minute angular fragments of mineral matter, or of rounded grains, or of a mixture of both angular and more or less rounded grains also bound together by mineral matter, which may either be amorphous or may possess a crystalline structure. . . . . There are, however, apparent exceptions, for some rocks appear to the naked eye to be perfectly homogeneous. Some quartzites may be so regarded, but we know that passages have been observed between quartzites and fine-grained sandstones. A casual observer might also take such a rock as Lydian-stone or Hone-stone to be quite homo-

* 'The Study of Rocks,' p. 7. Longmans and Co., 1879.

geneous, but examination of a thin slice under the microscope would show it to consist of numerous lenticular particles. . . . . Again, obsidians, pitchstones, and other vitreous rocks, would be assumed by the general observer to be perfectly homogeneous, but here again the microscope demonstrates that they contain fine dusty matter, microliths, and crystals in great quantity; so that even those rocks which are apparently exceptions to the general definition are found to conform to it in reality.'

Stratified rocks.—All rocks, or very nearly all rocks, belong to one or other of two great divisions: the aqueous, stratified, or sedimentary, and the igneous, intrusive, or eruptive.

All the stratified rocks, except those organically and chemically formed, were deposited as clay, pure or impure—as sand or gravel, which differ from each other only in the size of their particles—or as an admixture of the two, sometimes with the addition of lime or other secondary ingredient.

> *Clay* is simply mud derived from the waste of pre-existing rocks, and generally consisting of finely-comminuted silicate of alumina.
>
> When indurated by pressure more or less vertical to the lines of bedding, it becomes divisible into laminæ, and is termed *Shale.*
>
> When indurated by pressure in any other direction, it is *cleaved,* or becomes divisible into laminæ at right angles to such pressure, generally transverse or oblique to the planes of bedding, and is termed *Slate.*

'Bands of colour may sometimes be observed on the sides of Slates, often coinciding with slight changes of grain or texture; these mark its original stratification. But care must be taken

in field observations not to rely too implicitly on mere bands of colour in slate rocks, unless they coincide with bands of various texture, which may always be trusted to show the original layers of deposition.'—Jukes' 'Manual of Geology,' p. 220. See also an excellent cut at p. 221, representing the planes of cleavage and original stratification. (See also p. 160.)

Clay, with the addition of Carbonate of Lime, equal to one-tenth or more of its substance, becomes *Marl*, and in a dry state breaks up into cuboidal fragments.

Marl, when indurated, becomes divisible into laminæ, and is termed *Marl-slate*.

In whatever form clay occurs, whether unaltered, or as shale, or as clay-slate, it gives off, when breathed upon, an earthy or slaty odour which is unmistakable.

Sand, which is also derived from the waste of existing rocks, consists mainly of quartz with a slight admixture of other minerals. When finely-bedded, it has been deposited in tranquil water;* when the lines of stratification intersect each other at various angles, it is *false-bedded*, and has been formed in a current, fluviatile or marine. When exhibiting 'ripple-marks,'† it indicates littoral conditions of deposit; when bound together by a cementing material, it becomes *Sandstone*, or, if coarse-grained, *Grit*.

Gravel consists of pebbles derived from neighbouring rocks, angular or rounded according to the

* Except in the case of 'blown sand.'—See Jukes' 'Manual,' p. 378.

† Lyell's 'Students' Elements,' p. 21.

degree of trituration to which they have been subjected. It is formed by rivers, or by marine currents at no great distance from the shore.

When the particles are bound together by a cementing material, it becomes, if the pebbles be more or less rounded, a *Conglomerate or Pudding-stone*, representing a shore-line; if the fragments be angular, a *Breccia.*

Clay and sand mixed, in varying proportions, form *Loam, or Brick-earth.*

Rocks formed by organic or chemical agencies.—The rocks formed by chemical and organic agencies are principally Limestones, fresh-water and marine—gypsum, rock-salt, and coal—travertine, tufa, etc.

Limestone may either be a stratified deposit resulting from the waste of earlier limestones, a chemical precipitate from water holding in solution a bicarbonate of lime, or an accumulation of the shells of foraminifera and other minute organisms. It may be hard or soft, coarse or fine, earthy or crystalline—in the latter case it is called *marble.*

Limestone, when pure, consists of carbonate of lime; when of carbonate of lime and magnesia it is called *Magnesian limestone,* which, if crystalline, becomes a *Dolomite.* When rendered impure by an admixture of clay, it is termed an *Argillaceous limestone,* and when it contains a proportion of sand, an *Arenaceous limestone.*

In many limestones bands of flint and chert occur, either as beds, or as layers of nodules in the lines of bedding, or as filling veins and fissures which may run in any direction.

Igneous rocks.—The igneous rocks fall naturally into two divisions: (1) 'the crystalline, including granite, syenite, with all the once melted rocks like the lavas;' and (2) 'the fragmental, including the consolidated volcanic ashes, tuffs, and conglomerates.'*

The crystalline igneous rocks are either *plutonic*, *i.e.* have been solidified at a great depth, and are now exposed only by denudation, or *volcanic*, a term which implies that they have, in a molten state, overflowed the surface. They may be either *intrusive* among, or *interbedded* with, the rocks above and below them.

'An intrusive rock may occur in the form of a vein or dyke, a pipe or neck, a sheet, or an irregular amorphous mass. When it can be seen to intersect any of the beds of a series of strata, its intrusive character becomes at once apparent. But when it lies between stratified rocks, and assumes the form of a bed, some care is needed to make its intrusive character certain, for it might then be taken for an interbedded sheet. It is usually characterised by being much closer in grain near its junction with the other rocks than in the central parts of its mass. Again, the rocks lying upon it are hardened, and sometimes exceedingly altered, while detached portions of them are now and then found to have been caught up and entangled in the crystalline mass below. A truly interbedded sheet, on the other hand, is in fact a lava-bed which has been poured out at the surface, either on land or under water, and shows the distinctive characters of such a bed. Thus it is commonly rough and slag-like towards its top and bottom, and most compact about the centre. The beds lying upon it, having been deposited there after the emission of the lava, are not altered, have no portions of their strata entangled in the crystalline rock, but, on the contrary, may contain detached fragments of the latter.'†

* 'Outlines of Field Geology,' p. 50. Geikie, 1877.

† *Op. cit.* pp. 50, 51.

In mapping igneous rocks it should be borne in mind (until they are proved to be interbedded) that they behave at the surface in an irregular manner, very similar to that of the glacial drifts; their boundary must be closely followed, while the remarks upon the drifts (at pp. 57 *et seq.*) may in these cases also be found of some advantage.

Metamorphic rocks.—It is sometimes a difficult matter to decide whether or not a rock owes its present character to the agencies of metamorphism. 'The changes which sedimentary rocks undergo may be regarded as physical, as chemical, or as the result of physical and chemical agencies acting either simultaneously or at different periods.'—*Rutley.* Rocks originally deposited as sedimentary strata, and having afterwards been altered, behave on a large scale as do the unaltered deposits; *e.g.* 'they never, like (eruptive) Granite or Trap, send veins into contiguous formations.' —*Lyell.*

Rounded water-worn grains will be found in most rocks that have undergone metamorphism, and will distinguish them from those of igneous origin when not too compact for the grains to be visible under a lens. Whatever they may at one time have enclosed as fossils, they will now be found like the latter, 'wholly devoid of organic remains.'

'If the rock have a very decided platy structure, so that a blow with the hammer causes it to split much more readily in one direction than in any other, with a tendency to separate into many thin plates, the question which arises is, whether it be an aqueous rock formed by the successive deposition of many thin layers, or a metamorphic rock. If the former, it will probably be soft or easily broken, and the plates will run parallel

to and coincide with layers of different colour or texture, or with the grain of the rock. (See p. 156.) If, however, it be a metamorphic rock, it will probably be hard, and the plates more or less firm after separation from each other. If the faces of these plates be dull and earthy-looking, it is probably a slate or 'cleaved' rock. If, however, the faces glitter with a metallic lustre, and the rock have a crystalline or semi-crystalline texture, it will then be a schistose or crystalline schistose metamorphic rock.'*

Veins.—The mapping of lodes or metallic veins are very similar to that of the drifts and igneous rocks, as these also follow an irregular course, and it is further complicated in that they do not often appear at the surface. But it will frequently be found that they make more or less of a surface feature, as a ridge or hollow, according to the varying hardness and dip of the beds or masses in which they occur. Veins may be traced like other deposits, although with more trouble, by close traversing and careful search for indications in ditches, and on the surface. The 'vein-stones' peculiar to the vein being traced may be discovered and followed from point to point, and these will afford material assistance. The outcrop of veins can be mapped by these stones, as that of strata which abound in fossils is sometimes traced for long distances by weathered fragments cast out from drains and ditches or turned up by the plough.†

* 'Students' Manual of Geology,' Jukes and Geikie, 1872, p. 95.

† For a description of mineral veins, and much information concerning them, see chapter viii. in a treatise on Geology, by Philips, 'Cabinet Cyclopædia' (Longmans and Co.), 1846, pp. 120-164.

Beds of phosphatic nodules are examples, and Prof. Judd thus writes of the Serpentinus Beds of the Upper Lias: 'So abundant are these ammonites (*Am. serpentinus*, *Am. falcifer*, etc.), that when the land has been recently drained it is strewn with their fragments, and it is almost always possible by these means to detect the outcrop of the beds containing them, even in ordinary ploughed fields.'

A vein of ore, one inch thick, six feet long, and six feet high (= 1 square fathom), will measure three cubic feet; two inches thick, six cubic feet per fathom; and so on.

TABLE OF WEIGHT IN POUNDS PER SQUARE FATHOM OF ORE, ONE INCH IN THICKNESS.

Gold, Native	3281·25
Silver ,,	1875·
Copper ,,	1668·75
Copper, Vitreous	1050·
Copper, Pyrites	787·5
Copper, Red	1106·25
Copper, Grey	900·
Copper, Carbonate (Malachite)	712·5
Tin, Oxide	1256·25
Tin, Pyrites	825·
Lead, Sulphide (Galena)	1406·25
Lead, Carbonate	1200·
Zinc, Red oxide	1012·5
Zinc, Sulphide (Blende)	750·
Antimony, Grey oxide	843·75
Nickel, Arsenical	1406·25
Cobalt, Pyrites	937·5
Iron, Pyrites	912·75
Iron, Magnetic	1016·25
Iron, Arsenical	1068·75
Iron, Specular	912·75
Hæmatite	750·
Uranium, Oxide (Pitch-Blende)	1312·5
Barytes	750·

THE MORE COMMON METALS,

their usual modes of occurrence, and tests for approximate determination.

Metals are characterised by their peculiar (metallic) lustre and great specific gravity. Some few are found 'native,' but they usually occur in the state of ores, that is, in chemical combination with other substances; sometimes in veins in the older rocks, more frequently as concretions, or as interstratified beds.

The following Metals occur in a Native State:

Gold, Silver, } In plates, nuggets, grains, and threads among the older rocks, or alluvial deposits derived therefrom.

Platinum, in grains.

Copper, in plates and threads.

The following Metals occur as Ores in Veins:

Silver.

Copper, as Copper Pyrites, Glance, etc.

Lead, as Galena.

Iron, as Magnetite, Hæmatite, Siderite, etc.

Tin, as Cassiterite.

Zinc, as Calamine, Blende.

The following Metals occur as Ores, in Beds:

Copper, as Malachite, Pyrites, etc.

Lead, as Galena.

Iron, as Clay-iron ore, Calcareous or siliceous Iron-

stone, Pyrites, Glauconite (disseminated grains), Chalybite, Hæmatite, Magnetite, etc.
Manganese, as Pyrolusite, Wad.
Zinc, as Calamine, Blende.

Peculiarities of Structure observable in certain Rocks.

Concretions.—Frequently within the substance of a rock nodules of different composition, or perhaps only of different colour to the rock itself, may be found, of all sizes and varying in shape from flat and angular to perfectly spheroidal. These are 'concretions,' which sometimes consist of exactly the same material as the rock in which they occur, the form only of the future nodule being indicated by a slight separation of the particles, or by a faint band of colour. Such indications extend not only through many successive laminæ of a bed, but frequently, as the fully-formed concretions do, through even two or more beds of similar character. In other cases the nodule is seen to be more advanced in its formation, a considerable portion of one ingredient of the rock having been removed by chemical action and aggregated around the nucleus of the concretion. Again it may be seen in its complete state when all such ingredient has been segregated from the surrounding matrix and from the enclosed nucleus also, in some instances entirely altering their composition and appearance. And at a still later stage concretions may be noticed either wholly or partially decomposed, or they may have been entirely dissolved by water which, percolating through the mass, has carried away their substance in solution. The cast only then remains, and

this also may be modified by similar action and to any extent enlarged, or it may even be again filled with mineral matter by a process of infiltration.

These concretionary nodules occur in rocks of all ages, and as a rule consist of some substance which has previously formed a minor ingredient of the enclosing mass. Notable examples of concretions are the flints of the Chalk,* and the iron-stones of the Carboniferous and Oolitic formations, and of decomposed concretions, the limonite found in the Chalk, in many clays and other deposits as a ball of rusty-looking powder, into which the iron-pyrites has been converted by oxidation.

Concretions may be formed within concretions by further segregation of one particular substance, as, for instance, of sulphide of lead or of zinc in clay-iron-ore. As throwing light upon the composition and origin of the rock in which they are found, and on account of their commercial value, concretions are of considerable importance, therefore note should always be made of their occurrence.†

Slickensides.—The walls of a fault or of a joint may often be seen somewhat smoothed and finely striated in a direction generally transverse to the bedding; this is the result of one portion of the rock sliding up or down over the other during or after its fracture. But an appearance is sometimes observable which is very similar, although evidently not due to friction, as the striæ (or rather fibres) are continued into the substance

* Some notes, by the author, on the origin of the flints in the Chalk, will be found in the forthcoming Survey Memoir on the Geology of the country around Cambridge.

† *Ante*, p. 105.

of the rock; this may be due to 'crystallisation in parallel fibres,' or to recrystallisation as pseudomorphs after fibrous aragonite. The reality may easily be determined by removing a portion of the striated surface; if the fibrous structure be apparent within, the striæ are due to crystallisation—if not, to friction; and the fact should then be noted as evidence of some movement of disturbance.

CHAPTER II.

DETERMINATION OF MINERALS AND ROCKS.

Selection of Specimens—Cabinet Specimens—Tests—*Hardness—Streak—Effervescence—Texture—Structure—Fracture—Lustre—Specific Gravity—Chemical Analysis—Blow-pipe—Microscope.*

Selection of Specimens.—When it is desired to ascertain the kind of any rock exposed in a quarry, or elsewhere, a fragment should be detached from a part that has been least subjected to the action of the weather; for the composition of a 'weathered' surface may have been very materially modified. Some rocks will be thus changed into a substance totally different from their original state, and all are in colour and hardness more or less affected.

Having selected a suitable portion of the rock, let a good-sized piece be broken off by chisel or hammer; this can afterwards be reduced—its most characteristic-looking part being chosen—into a fair hand specimen. In using the hammer for this purpose, it should be borne in mind that the fracture will follow, as nearly as is possible, the line of the blow, the force of the descending implement (itself stopped by contact) passing on and operating in the same direction, unless turned aside by the mass being too rigid to be broken through. A fissile

rock may thus be split into slabs by blows on the edge; a piece broken off at right angles to the bedding by a direct blow on the surface; and a projecting corner may be chipped off a very hard and solid rock by well-directed blows, when otherwise fragments are unobtainable. It is also worthy of remembrance that one good swinging blow is more effectual than a dozen gentler taps, and the risk is no greater of a resulting fracture to the hammer-handle.

The rock to be determined should be broken, with as little chipping as may be, into a square fragment, not a rounded lump, the larger surfaces representing the lines of bedding, with the others at right angles to them, or thereabouts; and if the specimen is to be preserved, it should be of fair size, but not too large for portability. The best edge for observing the texture of the rock is thus obtained, but a weathered exterior will frequently reveal the grain when it is quite indistinct upon a freshly fractured surface—the more durable mineral, generally quartz, standing out beyond the others which have yielded more or less to the disintegrating action of the atmosphere.

Cabinet Specimens.—Specimens intended for future reference should be taken from a part of the rock observed in a quarry, or elsewhere, which presents in a typical manner its noteworthy features. They should represent the average colour, show distinctly the crystals, grains, or laminæ, and, if practicable, be collected from the heart of the rock: another piece should always be taken which shows a weathered surface. Pieces about two inches in length by one and a half inches in width and thickness are of convenient size,

but these must be as nearly as possible straight-sided and rectangular. When first detached and chipped into form, each specimen must be wrapped in paper with the locality, formation, and if possible the very bed whence derived, written thereon. A collection of rocks or fossils, simply as such and without their original locality being known, is utterly valueless for scientific purposes.

After all necessary tests have been applied for determination at home, each specimen should be labelled, or numbered with reference to a list. The label or reference must set forth, in this or any other convenient form, the kind of rock, the formation, and if possible the horizon, to which it belongs, with the locality from which it came.

Rock. *Oolitic Limestone.*
Formation. *Great Oolite.*
Locality. *Box Tunnel.*

TESTS FOR DETERMINATION OF ROCKS AND MINERALS.

Hardness.—The tests by which, in the field, the nearest approach can be made to the determination of a rock or mineral are its 'hardness' and 'effervescence.' The former is roughly ascertained by means of the steel blade of a pocket-knife, the latter by application of dilute nitric, sulphuric, or hydrochloric acid, the solution usually being about one part acid to five water. A mineral as soft as Talc or Gypsum may be scratched by the finger-nail; between those and Apatite, by the knife with ease; beyond that, and including Orthoclase

Felspar, with some degree of force; while those of greater hardness are not marked at all by the steel.

Precise determination of the hardness of a mineral is made at home by comparison of the specimen with others of which it is known, the scale arranged by Mohs being the one generally adopted.

Hardness Scale.

Scratched by the nail.	1. Talc, common foliated variety.
	2. Gypsum, crystallised variety.
	3. Calc-spar, transparent variety.
Scratched by the knife with ease.	4. Fluor-spar, crystallised variety.
	5. Apatite, transparent crystallised variety.
Scratched by the knife with difficulty.	6. Felspar (orthoclase), cleavable variety.
	7. Quartz, transparent variety.
Cannot be scratched by knife or file.	8. Topaz, transparent crystallised variety.
	9. Sapphire, cleavable variety.
	10. Diamond.

The test is made by 'rubbing the specimen over a tolerably fine-cut file, and noting the amount of powder, and the degree of noise produced by so doing. The less the powder and the greater the noise the harder will be

the mineral. On the other hand, a soft mineral will yield much powder, and but little noise. The noise and amount of powder should be compared with that produced by minerals which are used as standard examples. The trial may also be made by endeavouring to scratch the specimens enumerated in the list with the mineral under examination. If, for example, the mineral will scratch Felspar and will not scratch Quartz, it will have a hardness between 6 and 7.'*

Streak.—'During these ("hardness") trials the "colour" and "lustre" of the streak should also be noticed.'† 'When a mineral is scratched, the colour of the scratched surface frequently differs from that of the original surface, and if the abraded powder be rubbed on paper, it leaves a mark of a peculiar colour. This is called the streak, and in some of the metallic minerals it is very characteristic.'‡

> *Note.*—In all the Tables given in this and the following chapters the *averages* of hardness and specific gravity are inserted with the more simple of the tests for solubility and blow-pipe analysis. For ultimate determination of any particular specimen, when special accuracy is desired, recourse should be had to some of the works specially devoted to the subject, or to the professed mineralogist. A list is given at page 198 of some of the works which may with advantage be consulted upon Mineralogy and Petrology.

* 'Mineralogy.' Rutley, p. 39.

† *Op. cit.*, p. 40.

‡ 'Microscopical Structure of Rocks.' Mello. 'Pop. Sc. Review,' Jan. 1875.

Effervescence.—A drop of dilute acid applied to the fresh fracture of a rock or mineral will cause effervescence—rapid, if the specimen consist of pure carbonate (of lime or otherwise); slow, if only partly composed of carbonate; but none whatever if it be a sulphate or a silicate. The following table embodies in a general form the results of the tests for hardness and effervescence; it is easily remembered, and applies in the case of nearly all ordinary rocks; the exceptions are simple minerals which present well-marked characteristics. In practice, so many varieties are found, that they are incapable of a simple classification; but then judgment must guide the observer, and an acquaintance with cabinet specimens will be found of great service, surpassed only by actual field experience.

If a rock:—

Scratch *with ease* and effervesce *freely*, it is a Carbonate of Lime.

Scratch *with ease* and effervesce *slowly*, it is a Carbonate of Lime and Magnesia.

Scratch *with ease* and effervesce *not at all*, it is a Sulphate or Silicate.

Scratch *with difficulty* and effervesce *not at all*, it is a Silicate.

Scratch *not at all* and effervesce *slowly*, it is calcareous Sandstone, when granular.

Scratch *not at all* and effervesce *not at all*, it is a pure Silicate when crystalline, and Siliceous when compact.

Texture.—The rock or mineral is next examined for 'texture;' this may be very apparent, but if not readily

decided, it must be observed with a pocket lens of one, two, or three powers, as may be found requisite. This point should if possible be settled; but when doubtful under the lens, look for lines of varying colour as signs of stratification. The texture may be either—

Crystalline—in which all the component minerals are crystallised and apparent, as in Granite.

Crypto-crystalline, Half crystalline — 'where the rock is a devitrified glass, or a mass of imperfectly formed crystals.'

Glassy—resembling Glass, as in Obsidian.

Compact—or homogeneous, as in Flint.

Granular—made up of distinct and somewhat rounded grains, as in Sandstone.

Lamellar, Laminated — consisting of thin plates or layers, the laminæ being in the lines of bedding.

Cleaved—consisting of thin earthy-looking plates or layers, the laminæ being generally transverse to the lines of bedding, as in Clay-slate.

Foliated—consisting of thin crystalline plates or layers, the foliæ coinciding with the lines of bedding or cleavage, as in Mica-schist, etc.

Fibrous—resembling fibres, as in Fibrous Gypsum.

Earthy—soft and friable, as in Shale.

Porphyritic—enclosing larger embedded crystals, as in some of the Cornish Granites.

Vesicular—full of little cells or vesicles, as in Pumice.

Structure.—The 'structure' also of rocks must be noticed, by which term is meant, their mode of occurrence in the mass, which may be, either—

Bedded—in definite stratified beds.

Massive—in large masses broken in various directions.

Jointed—divided by joints into blocks.

Columnar—in which the blocks resemble columns.

Amorphous—in which no bedding or other definite structure is presented.

Slaggy—like furnace slag.

Scoriaceous—cinder-like in appearance.

Fracture.—The character of the 'fracture,' or broken surface, affords useful indication of the kind of the rock or mineral under examination, when taken in connection with its other peculiarities. The most usual forms of fracture are :—

Conchoidal —	(Shell-like) as that of	Flint.
Even - - - -	,,	Chert.
Uneven - - -	,,	Basalt.
Splintery - - - -	,,	Cast Iron.
Earthy - - - -	,,	Chalk.

Lustre.—After the texture and fracture of a specimen have been noted, the 'lustre' of its freshly-broken surface requires observation. This character, of which there are many kinds and degrees of each kind, serves to distinguish a rock, whether it possess a crystalline or any other texture. Lustre may be :—

Metallic—like the ordinary lustre of metals.

Sub-metallic.

Adamantine—like that of a Diamond.

Vitreous— ,, ,, Glass.

Sub-Vitreous.
Resinous—like that of Resin.
Pearly— „ „ Pearl.
Silky— „ „ Silk.

Specific Gravity.—The 'specific gravity' of a body being the proportion that its weight bears to that of an equal bulk of distilled water, at a temperature of 60° Fahr., which is taken as unity, it is evident that if such body be weighed, first in air, then in distilled water, the difference of weight represents that of an equal volume of the water, displaced by immersion. Therefore the weight of the substance in air is to the loss of weight (*i.e.* the weight of the displaced water) as the specific gravity is to unity—consequently the weight in air, divided by the loss, will give the required specific gravity.

A delicate balance on a stand with minute weights is required for the operation, one pan having a small hook beneath it, from which the specimen to be tested is suspended by a fine platinum wire; a few grains of sand, added after the thread is attached, will bring the scales into equilibrium. The actual weight of the suspended object is first to be ascertained, then there is placed beneath it a small vessel containing distilled water at the proper temperature, in such position that it shall be completely immersed during the second weighing operation.

Chemical Analysis.—Few remarks only will be made on this subject, for the necessary apparatus and reagents, without which detailed chemical analysis is impossible, will not be at the command of the geologist at work in

the field; but there are occasions when it will be necessary and will afford valuable information. It is the only way of ascertaining the ultimate composition of a rock, but it is work of a special nature, for which the aid of the analyst may well be sought, as the processes are generally tedious and require much experience.

There are, however, some rocks and ores of the metals which may be analysed without much trouble; the method of procedure is plainly given in the little work 'Analysis of Soils,' by Professor Johnston, mentioned in the list at page 199, and the subject is more fully treated in Bischoff's 'Chemical Geology.'

As a very useful addition to the particulars given under the head of 'Solubility,' in the Table of Tests, chap. iii., the following list of 'Reactions in the wet way' has been copied from Rutley's 'Mineralogy,' p. 22:

Substances.	*Reaction.*
Carbonates.	Effervesce when treated with dilute acids (either hydrochloric, nitric, or sulphuric), owing to disengagement of carbonic acid gas.*
Sulphates.	Do not effervesce on the application of acids, but when in solution,† a drop of chloride of barium will produce a dense white precipitate of sulphate of barium.

* Sulphides also effervesce with evolution of H_2S.

† As carbonates give the same reaction, any carbonate that may be in the solution must be first dissolved by the addition of a little nitric acid: it is then termed an 'acidulated solution.'

Substances.	*Reaction.*
Phosphates.	In solution give yellow precipitates on the addition of nitrate of silver or molybdate of ammonium. These reactions usually take some time.
Chlorides.	Give a white curdy precipitate when nitrate of silver is added to their solutions.
Fluorides.	When treated with strong sulphuric acid, give off fumes of hydro-fluoric acid, which roughen or etch glass.
Silicates.	Many silicates gelatinise when heated in concentrated acids. The silicate should be finely pulverised.

Blow-pipe.—One of the most useful agents in determining the species of a mineral is the blow-pipe, an instrument by which the specimen under examination can be subjected to great heat, in a flame that shall either oxidise it, or deprive it of its oxygen—the former being called the 'oxidising,' the latter the 'reducing' flame.

'The student ought to accustom himself to the use of the blow-pipe, as an instrument to aid him in the determination of rocks—much assistance may be obtained in this way. No field geologist should consider his outfit complete if it does not include a blow-pipe, with the requisite reagents.'—*Jukes.*

'The blow-pipe flame is produced by forcing a small continuous stream of air, by means of the blow-pipe, through the flame of a candle or lamp, and in a more or less inclined direction. The best flame for the purposes

of the blow-pipe operator is given by an oil-lamp with a broad and moderately thick rectangular wick, the lamp being supported on a small brass pillar. The principal points to be attended to in the production of a good flame are: 1. That the stream of air be constant and regular, and 2. That it be properly directed and applied. According to the mode in which the flame is produced, it is in the power of the operator to direct either an *oxidising* or a *reducing* flame upon the body he subjects to its action.

'In order to obtain a reducing flame (for depriving a substance of its oxygen) the nozzle of the blow-pipe is held in an inclined direction parallel to the surface of the wick and just touching the exterior surface of the flame—a bright yellow flame will be thus produced. An oxidising flame (for bringing about the oxidation of a substance) is obtained by keeping the nozzle of the blow-pipe at the same inclination as in the former case, introducing it into the flame to about one-third the breadth of the wick; it is desirable to blow a somewhat stronger blast than is required for the reducing flame—the flame so produced is of a pale blue colour and almost invisible by daylight.

'It is easy to understand the principles upon which the two different flames are produced, according as the operator manipulates in one or other of the modes above described. In the case of the reducing flame, the entire flame of the lamp is forced aside by a weak current of air impinging on its outer surface, and it is therefore unchanged except in direction; whereas, in the oxidising flame a strong blast of air is poured into the interior of the flame, which, becoming thoroughly intermingled

with the various inflammable gases evolved from the wick, produces an almost perfect combustion.

'If then a small fragment of an oxidisable substance be held just beyond the point of this flame it becomes intensely heated, and, being exposed freely to the action of the surrounding atmosphere, it is rapidly oxidised. This flame, on account of its great heating power, is also employed in order to ascertain the fusibility of various substances, and for effecting fusions in all cases in which a reducing action is not essential. When any substance is submitted to the action of the reducing flame it should be so held as to be entirely surrounded by the yellow flame, and protected from the oxidising action of the air; but this condition being fulfilled, it should be held as near as possible to the point of the flame in order to gain the greatest amount of heat.

'When the instrument is used the mouthpiece is pressed against the lips, or if this be wanting, the end of the stem must be held between the lips of the operator. Beginners usually commit the fault that while blowing, they do not close at the right moment the passage between the wind-pipe and the mouth, but blow for a longer or shorter period from the lungs alone. It is advisable that a beginner in the use of the blow-pipe should exercise himself in breathing regularly and audibly through his nose while keeping up a continuous blast by the muscles of the mouth, and continue this practice until he is able to do so without any perceptible exertion.

'To test the fusibility of a mineral, a small splinter having a sharp edge or point should be broken off and held in the forceps at a short distance beyond the point

of the inner blue flame, so that the sharp edge is strongly heated. If a powdered substance is to be tested, or one which decrepitates when heated, a small quantity of the powder is made into a paste with water and spread upon a piece of charcoal. It is then dried and strongly heated with an oxidising flame, and it will generally cohere sufficiently to allow of its being taken up between the forceps and tested in the usual manner. According to their relative fusibility minerals may be classed as follows:—

1. Readily fusible to a bead.
2. With difficulty fusible to a bead.
3. Readily fusible on the edges.
4. With difficulty fusible on the edges.
5. Infusible.

'In testing the fusibility of a mineral substance it should be noticed whether, if fusible, a clear or opaque bead is obtained; also whether the substance changes colour, becomes magnetic, or exhibits any phenomena of intumescence, ebullition, etc.'*

For blow-pipe analysis, yielding indications such as are given in the Table, on pp. 186 *et seq.*, much apparatus is not required; it consists of:—

Blow-pipe of brass or German silver, with platinum point.

Oil-lamp, with broad rectangular wick, on adjustable support.

Pieces of charcoal as supports for substances

* 'Scheerer and Blanford on the Blow-pipe.' 1864.

under examination, 5 or 6 inches long by an inch broad, made from close-grained pine wood.

'Charcoal is employed as a support where it is either required to reduce an oxidised substance or to fuse a body without oxidising it, also in many cases when it it desired to oxidise a body on which the reducing action of the charcoal alone is unimportant.'*

Platinum wire, a small coil or in lengths of about 2 inches, with one end bent into a small hook.
Platinum foil, about 2 inches by an inch, as a support for substances which it is desirable not to expose to the reducing action of charcoal.
Platinum spoon.
Magnet.
Brass forceps with platinum tips.
Glass tubes, ¼ inch diameter, some open at both ends, others at one end only.
Reagents, which must be *pure*, and kept in well-stoppered bottles: Carbonate of Soda, Borax, Microcosmic Salt; also Saltpetre and some others for full or special analysis, as described in the 'Introduction to the use of the Mouth Blowpipe,' by Scheerer and Blanford, a work from which these brief remarks and instructions have been extracted.

'When it is required to make a bead, in order that the powder may adhere to the platinum wire, the hooked end of the latter is heated and dipped into the borax. A small portion of the powder will be taken up, and this being fused and again dipped while hot into the powdered salt, a fresh portion will adhere,

* *Op. cit.*

and this process is repeated until a bead of sufficient size is obtained. The bead thus formed should be clear and pefectly colourless, both in the hot and the cold state. While the glass is still hot and fluid it is touched with a small quantity of the powder of the substance under examination, and that which adheres is fused into it. The operator must then observe, first, whether the substance be soluble or insoluble in borax; and secondly, the colour of the borax bead in (1) the oxidising, and (2) the reducing flame, both in the hot and in the cold state. In performing this experiment, care must be taken not, in the first instance, to dissolve up too large an amount of the oxide or other substance under examination. If a small quantity afford no distinct reaction, more may easily be added. If, however the colour of the bead be too intense to be clearly distinguished, the bead may be jerked off the wire, and that which still adheres fused up with a fresh quantity of borax, by which a paler and more transparent glass will be obtained.'*

Complete cases of Blow-pipe apparatus and reagents (which were awarded the Prize Medal of the Royal Society of Arts) are supplied by S. Henson, Mineralogist, 277, Strand, W.C., at £1 1*s.* and £1 12*s.* 6*d.*, or with extra drawer containing Minerals £2 2*s* 6*d.* These are very useful, convenient and portable cases, containing everything requisite for the purposes of geologists, travellers and explorers. Very useful, also, to the student of field geology, are the collections of Minerals, Rocks and Fossils, classified or stratigraphically arranged, which may be obtained, at all prices from a guinea upwards, from Mr. Henson, or from Professor Tennant, Mineralogist, 149, Strand, W.C.

Microscope.—'It often happens that neither the naked eye nor a good lens will help us to get at the composition and textural arrangement of fine-grained rocks, while the forms of analysis mentioned in the foregoing paragraphs are equally unavailing. In such cases much may be learnt by examining the rocks under

* *Op. cit.*

a microscope. For this purpose a thin slice of any rock which it is proposed to examine is taken, ground smooth, and polished on one side. The polished surface is then securely fastened with Canada balsam to a piece of plate-glass, and the other side is ground down until the section is of the required thinness and transparency. The preparation may be covered with a plate of very thin glass mounted with balsam on the slide, care being taken to exclude all air-bells, and to remove all traces of the emery powder and other substances used in the grinding and polishing process.

'A rock-section prepared in this way enables us to ascertain with precision the manner in which the different minerals are built into each other, and often throws a flood of light on the origin of a rock, and on the subsequent changes which it has undergone. It furnishes an opportunity of applying the delicate analysis of polarised light, and thus reveals points of structure in the composition of a rock which could not be ascertained in any other way.'*

'When prepared slices are examined under the microscope, it is often surprising to see how minerals which have previously been regarded, and even analysed, as perfectly homogeneous substances, envelop vast quantities of minute crystals of other minerals.† Here comes in the use of the microscope; by its means we also 'learn whether a rock, whose structure is too minute to be understood without it, is to be classed amongst the aqueous or the igneous series,' and we discover 'minute organisms,' such as foraminifera, diatomaceæ, or faint

* 'Students' Manual of Geology.' Jukes and Geikie. 1872.

† 'Mineralogy.' Rutley.

vegetable traces in rocks, in which, without its help, nothing can be detected. The broken and often water-worn fragments of the aqueous rock, derived it may be in the first instance from the breaking up of igneous rocks, will at once reveal its origin.

'Igneous rocks are for the most part crystalline in their structure, although we must at the same time remember that many crystalline rocks have been formed directly from watery solution. Gypsum, calcite, rock-salt, and some forms of quartz are examples of such, but those that have been thus formed may be readily distinguished. In his valuable paper "On the Microscopic Character of some Crystals," Mr. Sorby calls particular attention to certain minute cavities, in even the smallest crystals, which he shows to be the key to the history of the crystals.'*

Those who have the opportunity of making for themselves microscopical examination of rocks will find much valuable assistance in the monographs enumerated on p. 199, particularly in 'The Study of Rocks,' by F. Rutley, F.G.S., recently published, and at present the only English work specially devoted to the subject, where the apparatus required and the methods of research are fully and lucidly explained.

* 'Microscopical Structure of Rocks.' Mello. 'Pop. Sc. Review,' Jan. 1875.

CHAPTER III.

DETERMINATION OF MINERALS AND ROCKS—*continued.*

Tables of Tests, for the more common Rock-forming Minerals, Rocks, and Metallic Ores. List of Books of Reference.

Table of Tests, for the Determination of

Scratched by knife.	Effervescence.	Texture.	Fracture.	Lustre.	Colour.	Streak.
With ease	Rapid	Crystalline	Conchoidal	Vitreous to earthy	White or tinted	White or greyish
,,	,,	,,	Sub-conchoidal (Brittle)	,, to resinous	,,	Colourless
,,	,,	,, (fibrous)	Splintery	Silky	,,	,,
,,	Slow	,,	Conchoidal or uneven (Brittle)	Vitreous inclining to pearly	,,	White or grey
,,	,,	,, Sometimes Compact	Flat conchoidal	Vitreous	White or grey	White
,,	None	Compact, Foliated		Pearly (feels greasy)	White or green	Colourless
,,	,,	Foliated		,,	,,	,,
,,	,,	Foliated, Compact or Granular		,,	Dark olive-green	,,
,,	,,	Compact or Granular		Glistening or dull	Olive-green	,,
,,	,,	Foliated or Granular		Metallic	Iron-black or dark grey	Black and shining
,,	,,	Massive, pulverulent	Conchoidal (Brittle)	Vitreous	Green	Colourless
,,	,,	Crystalline, amorphous		,,	Sky-blue, sometimes greenish	,,
,,	,,	,, Massive or Granular		,, to resinous	White or tinted	White
	,,	Crystalline		Vitreous, some faces pearly	White	,,
,,	,,	,, or Compact	Conchoidal or uneven(Brittle)	Vitreous	White or tinted, frequently purple	,,
,,	,,	Amorphous	Flat conchoidal	Resinous	White or tinted	

THE MORE COMMON ROCK-FORMING MINERALS.

THE SUBSTANCE PROBABLY IS	Hardness.	Specific Gravity.	Solubility.	Behaviour before the Blow-pipe. Sundry Notes, etc.
CALCITE, Calc Spar (Carbonate of Lime)	2·5—3·5	2·6—2·7	Soluble in acid	Infusible, becomes luminous, and is reduced to quick-lime
ARAGONITE (Carbonate of Lime)	3·5—4·	2·93	"	Whitens and crumbles, in other respects as Calcite
Varieties:				
Satin Spar				
DOLOMITE (Carbonate of Lime and Magnesia)	3·5—4·	2·8—2·9	Sol. in warm acid	As Calcite
MAGNESITE (Carbonate of Magnesia)	3·5—4·5	2·8—3·	" "	Infusible, crackles and hardens
TALC (Bisilicate of Magnesia)	1·—1·5	2·5—2·9	Insoluble	Infusible, loses colour and emits light. Laminæ flexible, but not elastic
MICA (Silicate of Alumina, etc.)	2·—2·5	2·7—3·1	"	Infusible, loses colour and becomes opaque. Laminæ thin and elastic
CHLORITE (Silicate of Magnesia, Alumina and Iron)	1·5	2·6—2·8	"	Fuses on thin edges only. Laminæ not elastic
GLAUCONITE (Silicate of Iron and Potash)	2·	2·2—2·4	"	Fuses to dark magnetic glass
GRAPHITE, Black-lead (Carbon)	1·—2·	2·	"	Infusible. Laminæ thin and flexible
COPPERAS (Sulphate of Iron)	2·	1·8	Soluble in water. (Sol. blackens on addition of tinct. of galls)	Becomes magnetic, with borax yields a green glass
BLUE VITRIOL (Sulphate of Copper)	2·—2·5	2·2	" (Sol. coats clean iron with copper)	With soda reduced to a copper bead
BARYTES, Heavy Spar (Sulphate of Baryta)	2·5—3·5	4·3—4·8	Insoluble	Decrepitates, fuses with difficulty, colours flame yellowish-green
SELENITE, 'Satin Spar' (Sulphate of Lime)	1·5—2·	2·3	Slightly sol. in hydroch. acid	Exfoliates and crumbles, becoming white and opaque. Laminæ flexible and not elastic
FLUOR SPAR, 'Blue John' (Fluoride of Calcium)	4·	3·—3·2		Decrepitates and fuses to an enamel
ALLOPHANE (Silicate of Alumina)	3·	1·7—2·	Sol in dilute acid, in concentrated gelatinises	Loses colour and becomes pulverulent, colours the flame green

TABLE OF TESTS, FOR THE DETERMINATION OF

Scratched by knife.	Effervescence.	Texture.	Fracture.	Lustre.	Colour.	Streak.
With ease	None	Crystalline (radiating)		Pearly to vitreous	Blue or greenish	Bluish-white
With difficulty	,,	,,	Conchoidal, uneven (Brittle)	Vitreous to sub-resinous	White or tinted	White
,,	,,	,,	,, to uneven and splintery	Vitreous to pearly	White, pink	Greyish-white
,,	,,			Vitreous	Colourless (sub-transparent)	
,,	,,			,,	,, (transparent)	
,,	,,	,, (massive)		Dull vitreous	White	Colourless
				Vitreous to pearly	Tinted, exhibits internal reflections of colour	,,
,,	,,		,, (Brittle)	Vitreous to resinous	Greenish-black	Greyish
,,	,,	,, (foliated)	,,	Pearly	Green	
,,	,,	,, (foliated and massive)		,,	Brownish-green	,,
,,	,,	,, (massive and granular)			Greenish-black	Pale or colourless
,,	,,	,,	Sub-conchoidal	Vitreous or greasy	White or tinted	
Not at all	,,	,,	Conchoidal	Vitreous	White or tinted	Colourless
,,	,,	,, (columnar or granular)	Conchoidal to uneven	,,	Yellowish	,,
,,	,,	,, (massive or granular)	,,	,,	Grey or tinted	
,,	,,	,,	Conchoidal (Brittle)	Adamantine	White or tinted	

THE MORE COMMON ROCK-FORMING MINERALS—*continued.*

THE SUBSTANCE PROBABLY IS	Hardness.	Specific Gravity.	Solubility.	Behaviour before the Blow-pipe. Sundry Notes, etc.
VIVIANITE (Phosphate of Iron)	1·5—2·	2·6	Soluble in acid	Fuses, loses colour and forms magnetic globule. Thin laminæ flexible
APATITE (Phosphate of Lime)	5·	2·9—3·2	Soluble in nitric acid without effervescence	Infusible
FELSPAR, Orthoclase (Silicate of Alumina and Potash)	6·	2·4—2·6	Insoluble	Fuses with difficulty and only on thin edges, with borax forms a clear glass
Varieties:				
Adularia				
Sanidine (Glassy Felspar)				
FELSPAR, Oligoclase (Silicate of Alumina and Soda)	6·	2·6—2·7	,,	Fuses with difficulty to a clear glass
Varieties:				
Labradorite (Silicate of Lime and Soda)			Powder sol. in hot hydrochl. acid	Fuses to a clear glass
AUGITE (Silicate of Lime, Magnesia, etc.)	5·—6.	3·2—3·5		Fuses easily to grey glass
Varieties:				
Diallage				
HYPERSTHENE (Silicate of Magnesia and Iron)	5·—6.	3·3		Fuses to black enamel, on charcoal to magnetic mass
HORNBLENDE (Silicate of Lime, Magnesia, etc.)	5·—6.	2·9—3·4		Fuses easily to green bead, the dark varieties to magnetic globule
NEPHELINE (Silicate of Alumina, Soda and Potash)	5·5—6·	2·4—2·6	Becomes clouded in nitric acid, gelatinises	At edges fuses to a colourless glass
QUARTZ (Silica)	7·	2·5—2·8	Sol. in hydrofluoric acid	Alone unaltered, with soda dissolves with effervescence
TOPAZ	8·	3·4—3·6	Insoluble	Infusible
CORUNDUM (Alumina)	9·	3·9—4·2	,,	Infusible alone, in borax slowly forms a clear bead
DIAMOND (Carbon)	10· Scratches hardened steel.	3·5	,,	Burns at a high temperature

Table of Tests, for the Determination

TESTS, FOR APPLICATION IN THE FIELD.

Scratched by knife.	Effervescence.	Texture.	Fracture.	Lustre.	Colour.	Streak.
With ease	Rapid	Crystalline	Conchoidal	Vitreous to earthy	White or tinted	
,,	,,	Compact	Even	Earthy	,,	
,,	,,	Oolitic	,,	,,	Yellowish	
,,	,,	Earthy			White, sometimes grey or yellowish	
,,	Slow	Compact or Granular	,,		Various	
,,	,,	,,	,,	Dull vitreous to earthy	Brown or yellowish	
,,	None	,,	,,	Dull or glistening	Tinted	White
,,	None	Crystalline	Conchoidal	Vitreous	White, tinted	White
,,	,,	Earthy			Greenish-grey	Shining
,,	,,	Vesicular		Glistening	Grey	
,,	,,	Compact	Uneven	Resinous	Dark olive-green, spotted	
,,	,,	Cleaved	Splintery	Earthy	Dark grey	White
,,	,,	Foliated		Glistening	,,	
,,	,,	,,				
,,	,,	Massive	Uneven	Dull pearly	White or grey	White
,,	,,	Foliated			Green	
With difficulty	,,	,,			Black	
,,	,,	Compact		Vitreous, horn-like	Greenish-black	
,,	,,	Granular		Glistening	Various	
,,	,,	Massive		Resinous	Yellowish-green	White
		Concretionary			Brown	
		,,			,,	
,,	,,	Compact	Even	Dull	Tinted	
,,	Along inner border of weathered portion	Crystalline to Compact			Green, weathers brown	

OF THE MORE COMMON ROCKS.

TESTS, FOR FURTHER DETERMINATION AT HOME.

THE SUBSTANCE PROBABLY IS	Hardness.	Specific Gravity.	Solubility.	Behaviour before the Blow-pipe, Sundry Notes, etc.
LIMESTONE, Marble			Soluble in acid	
,, Common			,,	
,, Oolitic			,,	
,, Chalk			,,	
,, Argillaceous			,,	Emits slaty odour when breathed upon
,, Magnesian			Soluble in warm acid	
GYPSUM (Sulphate of Lime)	1·5—2·	2·3	Slightly sol. in hydrochl. acid	
ROCK SALT (Chloride of Sodium)	2·	2·2	Soluble in water	Decrepitates, tinges flame yellow
FULLER'S EARTH (Silicate of Alumina)	2·		Pulverises in water, but does not form a paste	Fuses to porous slag. Has a soapy feel
PUMICE, Lava froth (Orthoclase and Silica)		2·3	Insoluble	
SERPENTINE ROCK (Silicate of Magnesia)	3·—4·		,,	Fuses on edges with difficulty. Slightly soapy feel
SLATE (Silicate of Alumina)			,,	Clay (metamorphosed) Laminæ soft and earthy-looking
MICA-SCHIST			,,	Quartz and Mica, proportion varies
TALC ,,			,,	Quartz, Felspar and Talc
STEATITE (Soap-stone)	1·5	2·7	,,	Whitens and exfoliates, fuses on thin edges to white enamel. Has a soapy feel
CHLORITE-SCHIST (Soap-stone)			,,	Chlorite, with grains of Quartz, Felspar, or Mica
HORNBLENDE (Soap-stone)			,,	Hornblende, with Felspar or Quartz grains
HORNBLENDE ROCK			,,	Hornblende and Felspar
SANDSTONE, micaceous			,,	Quartz grains, with scales of Mica
APATITE (Phosphate of Lime) *Varieties:*	5·	2·9—3·2	Soluble in nitric acid without effervescence	Infusible
Phosphorite				
Coprolite				
Common Felspar			Insoluble	(See *Mineral Table*)
Diorite, Greenstone		2·6—2·9	,,	Felspar (not orthoclase) and Hornblende

Table of Tests for the Determination

TESTS, FOR APPLICATION IN THE FIELD.

Scratched by knife.	Effervescence.	Texture.	Fracture.	Lustre.	Colour.	Streak.
With difficulty	Along inner border of weathered portion	Crystalline to Compact			Greenish	
,,	,,	,,			,,	
,,	,,	,,			Dark grey	
		,,			,,	
		Compact	Conchoidal		Black	
,,	None	,,	Even	Vitreous	Grey, weathers white	
,,	,,	,,			Pink, brown	
,,	,,	,,	,, (feels gritty)		Grey	
,,	,,	,, or Schistose	Splintery		,, weathers white	
,,	,,	Glassy	Conchoidal	Vitreous	Brown or grey	
Not at all	Slow	Compact or Granular			Various	
,,	None	,,			White	
,,	,, (or very slight)	Crystalline, Granular				
,,	,,	Crystalline				
,, (or with difficulty)	,,	Compact				
,,	,,	Crystalline or Glassy	,,		White or tinted	
,,	,,	,,	,,		Black or grey	
,,	,, (or very slight)	Compact	Even			
,, (In parts with difficulty)	,,	Crystalline (foliated)				
,, ,,	,,	,,			Various	

OF THE MORE COMMON ROCKS—*continued.*

TESTS, FOR FURTHER DETERMINATION AT HOME.

THE SUBSTANCE PROBABLY IS	Hard-ness.	Specific Gravity.	Solubility.	Behaviour before the Blow-pipe, Sundry Notes, etc.
GABBRO, Greenstone		2·8—3·		Labradorite and Diallage
HYPERSTHENE ROCK, Greenstone		2·9		,, ,, Hypersthene
DOLERITE *Varieties:*		3·		,, ,, Augite (with some titaniferous Iron)
Anamesite		2·8		,, ,, ,, ,,
Basalt		2·9		,, ,, ,, ,,
FELSITE				Felspar (orthoclase) and Quartz
PORPHYRITE		2·6		Felspar (oligoclase), with Hornblende, Mica, etc. (rarely Quartz)
TRACHYTE		2·6		Felspar (orthoclase, commonly, var. Sanidine), with or without free Quartz, in former case called Quartz Trachyte or Rhyolite
PHONOLITE, Clinkstone			Partly sol. in hydrochloric acid	Felspar (orthoclase, commonly, var. Sanidine), with Nepheline and some Hornblende
OBSIDIAN		2·4	Insoluble	Felspar (orthoclase) and Silica, in a completely vitreous condition
SANDSTONE, calcareous			Matrix only sol.	Quartz grains in calcareous matrix
,, pure			Insoluble	Quartz grains
QUARTZITE, altered Quartz Sandstone			,,	
SILICATES } *Of some kind* Impure do. } *to be afterwards determined*			,,	
QUARTZ (Silica) *Varieties:*	7·	2·6	Soluble in hydrofloric acid	Infusible, unaltered
Flint			,,	
Hornstone, Chert.			,,	
GNEISS			Insoluble	Quartz, Felspar, and Mica, in laminæ more or less apparent
GRANITE		2·6	,,	Quartz, Felspar (orthoclase), and Mica
SYENITE			,,	Felspar (orthoclase) and

Table of Tests, for the Determination

TESTS, FOR APPLICATION IN THE FIELD.

Scratched by knife.	Effervescence.	Texture.	Fracture.	Lustre.	Colour.	Streak.
With ease	Rapid	Crystalline, etc.	Uneven	Vitreous, pearly	Brownish	White
,,	,,	Concretionary	,,	Earthy, dull	,,	
,,	,,	Compact or fibrous		Silky, dull	Bright green	Pale green
,,	,,	Crystalline	Flat, even	Metallic	Lead-grey	Lead-grey
,,	None	,, etc.	Conchoidal	Resinous to adamantine	Black or brown	White to reddish-brown
,,	,,	Compact or fibrous	,, uneven	Metallic	Bronze-yellow	Greenish-black
,,	,,	Crystalline	,, ,,	,, dull	Lead-grey	Lead-grey
,	,,	Compact	Fibrous	,, ,,	Black-grey	Black
With difficulty	Rapid	,,	Uneven	Vitreous, inclining to pearly	White, greyish, etc.	White
,,	With nitric acid	,,	,,	Vitreous, sub-pearly, sometimes adamantine	White, tinted green or bluish	,,
,,	None	Reniform	Sub-conchoidal or uneven	Sub-metallic	Steel-grey, red	Red
,,	,,	Crystalline, etc.	,,	Metallic, and highly splendent	Steel-grey, red, or iron-black	,,
,,	,,	Compact	Fibrous	Sub-metallic	Brown	Yellowish-brown
Not at all	,,	Crystalline	Conchoidal, uneven	Metallic to splendent	Bronze-yellow	Greenish or brownish-black
,,	,,	,, compact	Sub-conchoidal	Metallic or sub-metallic	Iron-black	Black
,,	,,	,,	Sub-conchoidal or uneven	Resinous to adamantine	Black or brown	White or grey to brownish

OF THE MORE COMMON ORES.

TESTS, FOR FURTHER DETERMINATION AT HOME.

THE SUBSTANCE PROBABLY IS	Hardness.	Specific Gravity.	Solubility.	Behaviour before the Blow-pipe, Sundry Notes, etc.
CHALYBITE, Spathic Iron ore (Carbonate of Iron)	3·5—4·5	3·7—3·9	Soluble in hot hydrochloric acid	Blackens and becomes magnetic. Iron 48 parts in 100 of pure ore (*Bloxam*)
Impure Varieties:				
Clay Ironstone				Contains 17 to 50 per cent. of Iron
Black-band ore				„ 21 to 43 „ „
MALACHITE (Carbonate of Copper)	3·5—4·	3·6—4·	Sol. in hot nitric acid	Decrepitates, fuses and colours flame green. Copper 58 parts in 100 of pure ore
GALENA, Lead ore (Sulphide of Lead)	2·5—2·7	7·2—7·7	Soluble in nitric acid	Evolves sulphurous fumes, fuses to metallic globule. Lead 86½ parts in 100 of pure ore
BLENDE, 'Black Jack' (Sulphide of Zinc)	3·5—4·	3·9—4·2	Soluble in hydrochl. acid	Infusible alone, decrepitates, evolves sulphurous acid fumes. Zinc 67 parts in 100 of pure ore
COPPER PYRITES (Sulphide of Copper and Iron)	3·5—4·	4·1—4·3	Soluble in nitric acid	Fuses to magnet. globule, evolves sulph. acid fumes. Copper 35 parts in 100 of pure ore
COPPER GLANCE (Sulphide of Copper)	2·5—3·	5·5—5·8	Sol. in hot nitric acid	Fuses to globule of Copper. 80 parts in 100 of pure ore
PYROLUSITE (Binoxide of Manganese	2·—2·5	4·8—5·	Soluble in acid	Infusible alone, with borax in outer flame gives an amethyst-coloured bead, inner flame forms white bead
CALAMINE (Carbonate of Zinc)	4·5—5·	3·—4·4	Soluble in hydrochl. acid	Infusible alone. Zinc 52 parts in 100 of pure ore
SMITHSONITE (Silicate of Zinc)	4·5—5·	3·2—4·5	Soluble in strong solution of caustic potash	Almost infusible alone
HÆMATITE (Per-oxide of Iron)	5·5—6·5	4·5—5·3	Soluble in acid	Infusible alone. Iron 70 parts in 100 of pure ore
SPECULAR Iron ore (Per-oxide of Iron)	5·5—6·5	4·5—5·3	„	„ „
LIMONITE, Brown hæmatite (Per-oxide of Iron)	5·—5·5	3·6—4·	Soluble in acid	Infusible alone. Iron 60 parts in 100 of pure ore
IRON PYRITES* (Bi-sulphide of Iron)	6·—6·5	4·8—5·1	„	Evolves sulphurous fumes, fuses to metallic globule, which is attracted by the magnet. Iron 46 parts in 100 of pure ore
MAGNETITE, Magnetic Iron ore (Proto-peroxide of Iron)	6·	5·	Soluble in hydrochl. acid	Infusible alone. Iron 72 parts in 100 of pure ore
CASSITERITE, Tinstone (Binoxide of Tin)	6·—7·	6·4—7·1	Almost insoluble	„

Useless as an ore, on account of the large quantity of sulphur it contains.

Many of the Minerals included in the foregoing Table of Tests are mentioned on p. 163, as occurring in veins or in beds; a list of the British rocks, in which the others are more likely to be found, is given below, and may serve to confirm the results obtained by the student in applying the tests tabulated for their determination.

Calcite—as calc-spar in veins, fissures, and filling cavities in septaria, in rocks of all ages.

Aragonite—in beds of gypsum, in iron-ores, in basalt and lava.

Magnesite—in serpentine and other magnesian rocks.

Talc—in talc-schist, protogine (talcose-granite), etc.

Mica—in granite, mica-schists, micaceous sandstones, and clays.

Chlorite—in granite, quartzose, and metamorphic rocks.

Graphite—in patches in granitic, trappean, and metamorphic rocks.

Copperas—in rocks containing iron-pyrites, by the decomposition of which it has been formed.

Blue Vitriol—in rocks containing copper-pyrites, by the decomposition of which it has been formed.

Barytes—in Mountain Limestone and other rocks, in veins with galena and other ores.

Selenite—in many clays as disseminated crystals, formed by the decomposition of iron-pyrites.

Fluor-spar—in veins traversing limestones and metamorphic rocks, frequently associated with galena.

Allophane—in chalk, clays, marls, and sandstones, encrusting joints, fissures and cavities.

Vivianite—in clay, peat, and with ores of iron, copper, and tin.

Apatite—in veins in granitic and metamorphic rocks.

Felspar—in granite and porphyry, and all igneous rocks.

Augite—in basalt, dolerite, and other trappean and volcanic rocks.

Hypersthene—in diabase, gabbro, etc.

Hornblende—in syenite, diorite, etc.

Quartz—in granite, in sandstone, and in veins in the older rocks.

Rock-salt—in Triassic rocks.

Steatite (soap-stone)—in serpentine, chlorite-schist, etc.

Serpentine (chrysolite)—in serpentine rock, and in granular limestone.

In collecting specimens of the rocks of any district, the student must be on his guard, or he may describe certain rocks as occurring there from his having found specimens which may be either 'fault-rock,' or 'vein-stuff.' Fault-rock is the material filling the fissure which sometimes exists between the walls of a fault, and may be a few inches only, or it may be several yards, in width. These fissures are filled with the waste of the rocks in which the fault occurs, or of rocks that at one time existed above them, with clay or sand sometimes in the state of compacted sandstone, or it may be with a mixture of the local rock-fragments with other mate-

rials that have found their way into the fissure. The fault-rock fragments are usually angular, although rounded pebbles are sometimes found in them, which have fallen in from the surface of the ground, or from the bed of the sea.

Vein-stuff is similar to fault-rock in being compact and in having had a similar origin, sometimes also enclosing pebbles and even fossils; veinstones or spars are usually quartz in siliceous rocks, calcite in limestones, fluor-spar, barytes and other minerals associated with pyrites and other metallic ores. (For detailed description of mineral veins, see a chapter on that subject in Jukes' 'Manual of Geology,' p. 290.)

LIST OF BOOKS OF REFERENCE,

WHICH, AMONGST OTHERS, WILL BE FOUND OF SPECIAL SERVICE TO THE FIELD GEOLOGIST.

GEOLOGY AND LITHOLOGY. *Principles of Geology.* Lyell. (Murray.)
Students' Elements of Geology. Lyell. (Murray.)
Manual of Geology. Jukes and Geikie. (Black.)
Geology. Philips. (Miller's edition.)
" Richardson.
" Green.
Geology of England and Wales. Woodward. (Longmans.)
How to Observe—Geology. De la Beche.
Glossary of Mineralogy. Bristow. (Longmans.)
British Mineralogy. Grey and Lettsom.
System of Mineralogy. Dana. (Trübner and Co.)
Text Book. " " "
Mineralogical Tables. Jewsberry. } (Murby's series.)
Mineralogy. Rutley. }

The Study of Rocks. Rutley. (Longmans.)

Determination of Minerals by the Blow-pipe. Fuchs. Translated by Danby. (Field and Tuer.)

Introduction to the use of the Mouth Blow-pipe. Scheerer and Blanford. (Williams and Norgate.)

Treatise on the Use of the Blow-pipe. Griffin.

Rocks classified and described. B. von Cotta.

Handy-book of Rock Names. Kinahan.

CHEMICAL ANALYSIS. *Chemical Geology.* Bischoff.

Analysis of Soils, etc. Johnston. (Blackwood.)

Agricultural Geology and Chemistry. Johnston.

MICROSCOPE. *The Study of Rocks.* Rutley. (Longmans.)

Microscopical Petrography. Ferdinand Zirkel. (Washington.)

On the Microscopical Structure of Crystals, indicating the origin of Minerals and Rocks. Sorby, 'Quarterly Journal Geological Society,' vol. xiv., pp. 453—500.

The Microscope in Geology. Forbes. 'Popular Science Review,' October, 1867.

On the Microscopical Structure of Rocks. Mello. 'Popular Science Review,' January, 1875.

Communications to the Geological Society, by Bonney, Judd, Ward, Rutley, and others. 'Quarterly Journal Geological Society.'

Articles in the 'Geological Magazine,' by Hull, Allport and others.

PALÆONTOLOGY. See the List in Part IV., p. 241.

Lowry's *Charts of Characteristic British Fossils,* and of *British Tertiary Fossils, stratigraphically arranged,* will be found very useful, and, owing to their portability, easy of reference, where larger volumes are not accessible.

LEVELLING, ETC. *Civil Engineering.* Rankine. (Griffin and Co.)

Mathematical Instruments. Heather. (Virtue and Co.)

WATER-SUPPLY, SCENERY, ETC. *Physical Geology of Great Britain.* Ramsay. (Stanford).

Physiography. Huxley. (Macmillian).

Water and Water-supply. Ansted. (Allen).

The Water-bearing strata of London. Prestwich. (Van Voorst).

On the Geographical conditions affecting the Water-supply to Houses and Towns. Prestwich. (Parker).

The Geological Record, an annual publication, commenced in 1874, is valuable as supplying short abstracts indicating the scope and nature of works on Geology, Mineralogy and Palæontology, published during the year. Whitaker. (Taylor and Francis.)

PART IV.

PALÆONTOLOGY.

By A. J. Jukes-Browne, B.A., F.G.S.

CHAPTER I.

Introduction—Nature of Fossil Remains—Review of Animal Kingdom—Petrifaction and Preservation of Fossils—Casts and Impressions—Distortion of Fossils.

Introduction.—Palæontology may be defined as the knowledge of fossil organisms, and of the laws which regulate their occurrence in the earth's crust; an acquaintance with these is of great service to the geologist, whether he be concerned with questions which are of theoretical interest, or of more practical importance. No treatise on field-geology would be complete without some chapters on palæontology, for it assists the observer in ascertaining the conditions under which any bed or series of beds were deposited, and in deciding many questions regarding their age and mode of formation which would otherwise remain obscure.

It is necessary that the palæontologist should be acquainted with the structure and habits of the various tribes, genera, and species now existing upon the globe,

especially of such as are most nearly allied to those occurring in the fossil state; then a study of the fossil contents of a bed tells him at once whether the formation was marine, estuarine, lacustrine, or terrestrial. In the three former cases the fossils will be for the most part remains of invertebrate aquatic animals, and an examination of the number and forms of these will greatly help him to form an opinion as to whether the rate of deposition was slow or rapid, whether the water was deep or shallow, near shore or far from land. Finally, an acquaintance with the different faunas and floras, which have at different times inhabited, and formed part of the general succession of life upon the earth, enables the palæontologist to estimate the relative age of any particular group of fossils, and to assign them to their probable place in the geological series. There are few formations or deposits of any thickness that are entirely destitute of organic remains, and in districts where the succession of the rock-groups is not fully known, the fossils obtained from the different localities visited form the only reliable data upon which an opinion can be founded. Even in cases where the relative position of the beds is easily ascertained, the evidence afforded by the fossils is of great use in confirming the conclusions derived from an examination of the rocks themselves, and in correlating the various subdivisions of the geological series.

The important doctrine that strata may be identified by their fossil contents was first taught by William Smith, and is thus expressed in a sentence extracted from his 'Stratigraphical System:' 'Organised fossils are to the naturalist as coins to the antiquary; they are the

antiquities of the earth, and very distinctly show its gradual regular formation with the various changes of inhabitants in the watery element.'* Before we can apply this highly useful doctrine to any particular series of beds, and before we consider any further the ultimate use of such investigations, we must become conversant with the nature and mode of occurrence of fossils, and with the ways and means of collecting them. The following observations therefore give some information on these several points, and show how, by a systematic method of procedure, the field-geologist may furnish materials for subsequent study, whether he works out the results for himself, or leaves them to be dealt with by a professed palæontologist.

We must here remark, that palæontological results, however carefully and thoroughly worked out, should never be taken as conclusive without being confirmed by the facts of stratigraphical evidence, as far as these can be ascertained. But their importance must not be underrated, and we would impress upon every geologist the desirability of obtaining all the fossils he can from any series of beds, and of making his study of them concomitant with his investigation of stratigraphical details. It is not necessary, however, that he should always collect all the fossils himself; another person may be employed for the purpose of visiting and collecting from the quarries and sections noted in the survey of the area, care being taken to see that the fossil-collector proceeds in accordance with the instructions hereafter

* See also a paper on 'Strata identified by Organic Remains,' by H. M. Jenkins, in 'Quarterly Journal of Science' for 1865, No. VIII.

given. It is important, moreover, that fossils should be collected not only from localities and beds where they happen to exist in an exceptionally good state of preservation, but also from every bed in the series, even where they are of an obscure nature or in a fragmentary condition. In this way the geologist will acquire knowledge which will lead to a thorough and philosophic description of the rocks composing the area upon which he is engaged, and will enable him to understand aright its physical, stratigraphical, and palæontological peculiarities.

I. *Nature of Fossil Remains.*—Fossils have been defined as 'organic remains buried in the earth,' the operations of natural causes being of course understood, and no limitation as to the subsequent lapse of time, nor any reference to their present state, being allowed to enter into the definition; since, as Mr. Jukes has well observed, 'any accumulation of shells, or bones, or plants, which could be said to be buried in the earth by any other than human agency, even if that burial took place last year, would be well worth the attention of the palæontologist.' Our first inquiry must have reference to the nature of these remains, the particular organic forms which are likely to occur as fossils and the various states of preservation in which they are found.

It is not every buried organism that leaves behind it a permanent record of its previous existence, and only those animals which contain a bony skeleton, or are enclosed in a hard shell or test, can as a rule become definitely fossilized; while plants and those animals which do not possess any such hard structures are rarely

found, except in the form of impressions or tracks on the surface of beds—the peculiar mineralisation which woody matter undergoes being of course an exception to this statement. Again, the nature of the remains or records of past existences will naturally vary according to the class of animals by which they were originated, and setting plants aside for the present, it will be worth while to review the animal kingdom for the purpose of seeing what groups are likely to be met with in the fossil state, and which of them so occur in greatest frequency and abundance.

Review of Animal Kingdom.

Vertebrata.

Mammalia—occur rarely, except in recent fluviatile deposits, and then generally in the shape of separate bones and teeth.

Aves—from their aërial existence, are still rarer as fossils, bones seldom occurring; but their footprints and even impressions of their feathers are known.

Reptilia.—Remains of all recent and extinct orders are tolerably abundant, except the *Ophidia* and *Lacertilia;* their bones, teeth, scutes, and in some cases their eggs and coprolites, being found.

Amphibia—are represented in certain formations by their bones and teeth, as well as their tracks or footprints.

Pisces.—The bones, teeth, and scales of fishes are common in almost every formation, from the Silurian upwards.

Invertebrata.

Mollusca.—Remains of all those classes possessing internal or external shells are very abundant; the *Tunicates*, being soft-bodied, are alone unrepresented.

Annulosa.—Of *Insects*, the skins, limbs, and wings are occa-

sionally found; of *Myriapoda* and *Arachnida* remains are very rare; of *Crustacea*, the limbs and carapaces are frequently found.

The *Annelids* are only known by the shells of *Tubicola*, and by the tracks and burrows of other orders.

Annuloida.—*Echinoderms* are frequent fossils, leaving remains of their tests, stems, arms, or spines.

Scolecida, having no hard parts, are quite unknown.

Coelenterata.—The *Actinozoa* present abundant remains of their hard skeletons or corals; but the *Hydrozoa*, being mostly soft-bodied, have left few traces. *Graptolites* are the chief exception.

Protozoa—are chiefly represented by the spicules of Sponges and the minute tests of Foraminifera.

Since the majority of rocks are of aqueous and principally marine origin, we should naturally expect the fossils which they contain to be the remains of aquatic and principally marine beings; and among the animals known to occur in a fossil state there is a large preponderance of marine forms. Thus, in the Vertebrata, the remains of mammals and birds are among the rarest of geological relics, even in beds of littoral or terrestrial origin, save those of very recent date; on the other hand, marine reptiles and fishes are found in almost all the later fossiliferous deposits, their vertebræ, scales, and teeth being occasionally very abundant. They seldom occur, however, in anything like a perfect condition, except in certain strata which have been formed quietly and rapidly enough to envelop them before dismemberment.

Among the Invertebrates, the group that is by far the most important and useful to geologists is that of the Mollusca. Most of the members of this class possess a

complete exo-skeleton, commonly called the shell or test, and as this usually is left in a more or less perfect state after the death of the animal, the fossil remains are more complete than those of the Vertebrate classes. The shells of Mollusca occur in almost every stratum which contains any fossils at all, and they present an immense variety of generic and specific types, so that a different set of forms is displayed in every successive group of rocks. They are, therefore, eminently qualified to form a scale of comparison by which the strata may be classified, and each referred to its proper position.

We have seen that William Smith likened fossil organisms to coins and antiquities, and we may carry the analogy still farther by saying that the remains of Mollusca especially are to geologists as the numismatic relics of a kingdom which has lasted from the earliest dawn of life to the present day.

Corals and Echinoderms occasionally occur in considerable profusion, and sometimes form great thicknesses of rock; crustacea are of more limited occurrence, most abundant in beds of littoral origin, but rare in sandy strata, and often absent in deep-sea deposits. Foraminifera are of very general distribution, and occur in all kinds of sedimentary rocks except those of a purely arenaceous character. They are not, however, of much practical use to the geologist, partly because of their minute size, and partly because they do not present such a varied series of types as are found among the members of more highly organised classes.

II. *Petrifaction and Preservation of Fossils.*—When organisms have once become buried in sedimentary deposits, and their soft parts have decayed, it

might be thought that the hard portions would then remain unchanged. This, however, is not the case ; they have in most instances been subjected either to contemporaneous or subsequent mineralising processes, by means of which they are more or less hardened and petrified.

It often happens that the animal matter, in decomposing, has given rise to chemical reactions, which have resulted in the formation of fresh mineral matter and its concentration round the body of the organism. In such a case the animal becomes included within the mass, and its harder parts, being usually preserved from further change, are disclosed on the splitting open of the nodule or concretion thus formed. Where, however, this does not take place, and the fossil is simply enclosed in the ordinary matrix of the rock, it is liable to more or less subsequent alteration. In pure clays this change is generally slight, simply consisting in the complete abstraction of the organic constituents ; and if the test or skeleton is siliceous, little alteration is effected. In other rocks, and where the shell or test is of a calcareous nature, it frequently happens that the whole of it has disappeared, and has either been replaced by other mineral matter, or else the space which the shell once occupied is left open, and nothing remains but the external impression and the internal cast formed of the material which filled up the empty shell.

Fossils, therefore, may be considered as occurring chiefly in four different states or conditions, viz.:

1. As unchanged shells or tests.
2. As replaced shells or 'pseudomorphs.'
3. As internal casts.
4. As external impressions.

1. *Unchanged Fossils.*—These may at once be distinguished from those that have been replaced by their mode of disintegration; they peel off in concentric layers, and disclose the original lamellar or cellular structure of the shell. Crag fossils and those of many sands and clays occur in this state of preservation, and are quite unaltered save by the abstraction of all the organic matter, for which reason they fall to pieces very easily.

2. *Replaced Fossils.*—Those that have undergone replacement split with a definite angular cleavage quite through the shell. The fossils of the Chalk, for instance, though still calcareous, split in this way, and the bivalves have moreover entirely lost their internal nacreous layer, so that no traces of the hinge or muscular impressions are, as a rule, visible. In other limestones this calcitic cleavage is still more marked; rhombohedral fragments may be chipped out of the thicker shells or from the tests and spines of Echinoderms, while perfect crystals may often be found inside. In sandstones the shells are often completely replaced by chalcedonic silica, as is the case with the fossils of the Blackdown Greensand.

The agency which produces such changes is water charged with carbonic acid and holding in solution the various mineral substances above mentioned; this acidulated water, percolating through the rocks, gradually dissolves the carbonate of lime composing the shell, and in many cases replaces it, particle by particle, with the other mineral which it contains in solution, and which is thus exchanged for the carbonate of lime. In other cases the material of the shell may have been entirely removed without any concomitant replacement,

the calcite, silica, or other mineral having been subsequently introduced into the vacant space, filling it up as it would any other cavity in the rock. But to explain the change of structure in some calcareous shells which are not wholly replaced, it seems necessary to suppose that the percolating water contained a saturated solution of carbonate of lime, some of which crystallised out in the cellular interspaces of the shell, binding the whole and imparting to it a crystalline structure, just as the sand of Montmartre, being infiltrated by sulphate of lime, is gathered together by crystalline action into rhombohedral prisms, taking the form of selenite.

3 and 4. *Casts and Impressions.*—The internal cast and external impression may be considered, as they nearly always exist together, whether the shell be unaltered, replaced, or removed; they are of course very much better seen and realised in the latter case, when the cast is loose or nearly so, and may be taken out of the cavity, thus revealing the impression or reversed fac-simile of the external form of the organism that once filled the empty space.

Suppose, for instance, we are dealing with the remains of a bivalve shell, such a Trigonia in figure 29, we find that the cast exhibits two raised ledges occupying the position of the muscular impressions, connected by a slightly raised ridge, corresponding to the pallial line which marks the attachment of the animal's mantle; the interspaces between the teeth will also appear, and sometimes concentric or radiating ridges answering to those of the shell itself. In the same way the internal structure of any hollow body, whether coral, univalve shell, or echinoderm, is faithfully represented by its cast,

and where opportunities for comparison exist, its genus and even its species may in many cases be ascertained.

While the internal cast thus exhibits in relief all the markings and irregularities which existed on the inner surface of the shell or test, the external cast or impres-

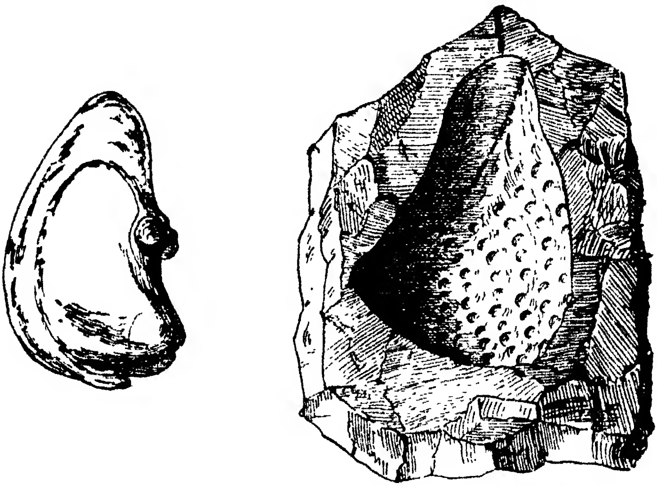


Fig. 29. Trigonia clavellata, Kimmeridge Clay. Cast and Impression.

sion is indented by all the markings which ornamented its outer surface. Where the shell is absent, therefore, and we wish to gain an idea of its appearance in relief, we can effect this by taking an artificial cast from the external impression, and thus obtain an accurate representation of the pre-existing shell.

In the majority of cases, where the sediment has had access to the interior of the shell, the cast consists of that material more or less compacted; but with such shells

as those of Cephalopoda, where the internal chambers have no communication with the exterior, the process of petrifaction has usually led to their being filled with some definite mineral, such as Calcite, Silica, or Iron-pyrites. Every one is familiar with the shining pyrites casts of Ammonites from the Oolitic and Cretaceous clays, and with others which have been cut and polished to show the chambers full of calcite spar.

Distortion of fossils.—Besides the changes indicated as affecting the shells and other fossils individually, the alterations which sometimes take place in the structure of the rocks must also be taken into consideration. The most important are those which result from the influence of pressure. For instance, in the Chalk, the effects of pressure may often be perceived; a collection of *Ananchytes ovatus* from the Upper Chalk will exhibit great differences of form, some of the variations being no doubt due to original differences, but others to the subsequent squeezing and crushing. The fossils of the Lower Chalk are often still more distorted, *Terebratulæ* being bent and twisted as if the shell had been elastic, and *Echinoderms* sometimes so crushed that their specific identity can hardly be determined. Occasionally, in softer strata, where the pressure has been more even and regular, the phenomenon is exhibited of an internal cast, showing all the characters of an external shell. It would appear in these cases that a thin shell having been dissolved out, the impression of its exterior has been gradually and equally squeezed on to the still soft mud inside; this, on the desiccation and consolidation of the rock, would present every appearance of the original fossil, though the closest examination would

reveal no traces of shell structure; instances are found in some fossils from the Chalk-marl and from the Bracklesham Beds in the Isle of Wight.

Where the rocks have been subjected to great strain, causing the strata to be bent or contorted, the effect on the fossils is often very remarkable; these are more or less flattened, stretched, and pulled out of shape; we have, for instance, in our possession an Ammonite from the Grey Chalk near Freshwater, in the Isle of Wight, where the beds are bent into a strong uniclinal curve, and the fossil is in consequence so crushed and distorted that, instead of being round, its longer is three times the length of its shorter diameter. We have here an approach to the effects of cleavage, and it has been demonstrated by Mr. Sorby and others that the phenomena of cleavage have been produced by the same cause, viz., the influence of great pressure. Fossils obtained from cleaved rocks are sometimes elongated and distorted in an extraordinary manner, the compression being always greatest in a direction perpendicular to the planes of cleavage.

Mr. D. Sharpe and Professor Haughton have investigated this subject, and the latter has enunciated the two following laws:

'1. The greatest distortion or elongation of fossils lying in the plane of bedding is parallel to the intersection of this plane with the plane of cleavage.

'2. The distortion of fossils estimated in a given direction (such as parallel to the intersection of the planes of bedding and cleavage) varies with the angle between these planes, being greater when the angle is greatest, and less when the angle is least.'

A consideration of these laws and an inspection of

any set of fossils from slaty rocks, will show that the variation of shape induced by cleavage on individuals of the same species is almost infinite, since it is rare to find two specimens lying in exactly the same position with regard to the planes of bedding, and every little difference in such position will have resulted in a corresponding difference in the shape ultimately produced by the force of pressure. It is clear therefore that in identifying such fossils, it is necessary to make careful allowance for this distortion; indeed their determination is often a matter of great difficulty, requiring the knowledge which is only gained by practice and experience.

CHAPTER II.

HOW TO COLLECT FOSSILS.

Apparatus for collecting fossils—Hints and instructions—Examples of collecting in pits and quarries.

I. *Method of Collecting Fossils.*—In Part II. p. 105, the mode of procedure in examining natural or artificial sections was described, and it was pointed out that notes should be taken of the nature and contents of the rocks therein exposed; also that these open sections must be closely searched for the fossil remains which the several beds may contain. Although it is not often that every separate bed or layer contains definite remains of fossil organisms, yet there are few without some traces of animal life, and even in a limited series of strata there is usually one at least which contains them in greater or less abundance.

For the collection of fossils certain tools and apparatus are necessary, and these differ according to the nature of the rocks that are likely to be met with in the area surveyed. Among hard rocks, or even those of moderate compactness, a hammer and chisel will of course be required, but where only soft clays or marly sands are to be explored, a good strong clasp-knife or a long fern-trowel will be found a more effective instrument for extracting the fossils they may contain. Paper is

needed for wrapping up the larger and stronger specimens, and a few small boxes should be taken, with a little wool or soft paper, in which the smaller and more delicate specimens may be stowed. Ordinary chip boxes are perhaps as useful as any for this purpose, and as they are sold in nests of different sizes they have the advantage of being easily carried; but sometimes stronger cases are necessary, when those in which baking powder is sold will be found serviceable.

This apparatus may all be carried in a bag slung across the shoulders, but where large finds are expected, and especially among the older rocks, a fisherman's basket is admirably suited for such service, since in this the various fossils and rock-fragments can be securely packed as collected, thus preventing their tendency to shake about and scratch one another during further exploration.

Great care should be taken to keep separate the fossils obtained from different beds and localities, and a note of the bed and locality should be immediately written in pencil on the paper or box in which they are enclosed. Where several fossiliferous beds are exposed in a quarry, it is a good plan in the first instance to number them, from the bottom upwards, and the packages of fossils obtained from each bed also, to correspond with those numbers in the note-book. Unless the specimens can at once be cleaned, identified, and placed in the drawers of a cabinet, it is desirable to ink over all these references at the end of each day's work, or to rewrite them on a second wrapper, they can then be stowed away until the collector finds time to prepare and label them properly.

When fossils are extracted from hard rocks, and are

detached in lumps or fragments of considerable size, they should only be reduced and roughly trimmed according to the dimensions of the enclosed organism, leaving further manipulation until the specimen arrives at its destination, for the final trimming often requires to be done very carefully, so as not to damage the fossil. A skilful handling of the hammer and chisel is indeed only to be attained by much practice, and the ultimate development of a specimen is a more or less delicate operation, from which it does not always escape uninjured.

In collecting among cleaved rocks, it is desirable occasionally to break the fragments across their cleavage, in order to detect fossils that may be lying in the planes of bedding, as is frequently the case; or the fossils so placed may otherwise escape notice altogether.

In chiselling anything out of a soft rock like chalk the chisel should be directed away from the fossil, so to extract a larger lump than may at first sight seem necessary, otherwise the rock may flake up and destroy the specimen; when safely extracted, it should then be slightly trimmed, wrapped in paper, and stowed in the bag or basket. With still softer rocks, such as shales and clays, the specimens can at once be reduced to the proper size by means of the knife; and then, if carefully conveyed, will need little further attention, unless some preservative, such as gum or gelatine, be required for their ultimate conservation.

For fossils that are found in loose sands, loams, and marls, whether freshwater or marine, more care is needed; in the first place all matters connected with their mode of occurrence should be noted before they are extracted

from the matrix; *i.e.*, whether the bivalve shells stand in the natural position of growth with both valves united, or whether they are single valves and drifted shells; whether there is a large or small proportion of water-worn specimens; whether or not they are associated with mammalian remains. Such mammalian teeth and bones when first obtained are sometimes sufficiently strong to bear ordinary carriage (though they should always be soaked in gelatine afterwards), but the smaller fossils are usually in a friable condition, and these should be immediately packed in boxes with wool, bran, or saw-dust. Where these materials are unattainable, clean sand from the shore or pit itself may be used as a fair substitute, though it has the disadvantage of being much heavier. Occasionally, too, the mammalian bones are very friable, and require much care in their removal.

We have hitherto spoken of the fossil remains which are actually included in the matrix of the bed or stratum, and were deposited there in most cases after the death of the animal, and during the accumulation of the materials which form the matrix. But since every layer of a sedimentary rock once formed the bottom of a river, lake, or sea, we should naturally expect to find some fossils resting on their surface in the position of growth, as well as the tracks of animals which also come under the category of fossils. These, of course, will be seen by separating the layers which compose the series of strata under examination, or may be found on the surface of beds already exposed. The Dudley slabs are good examples of this, and other instances are often found in the shales and limestones of the Oolitic series.

In quarries of sandstone, flagstone, or mudstone, where, perhaps, actual fossil remains are only met with at rare intervals, the surfaces of exposed beds will sometimes exhibit an interesting series of impressions, such as the footprints of birds and reptiles, the tracks left by crustacea or made by the pectoral fins of fishes, the trails of molluscs and annelids, and the burrows of various worms. These tracks and trails have not yet received the attention which they deserve, and it is possible that more extended and more careful observations in rocks of all ages would throw light on some of the more obscure fossils in Palæozoic formations.* All such markings should be studiously noted, for they afford distinct evidence of the existence of certain orders of creatures, the individuals of which may or may not have left other more determinable relics.

In collecting from beds at the junction of two dissimilar deposits there are matters deserving of special attention: if there is a marked line of separation between them we may be sure that there was an interval of greater or less length between the formation of the two beds; if the lowermost rock should be any variety of limestone, it is not unlikely that it may in

* Those curious fossils, for instance, which are found in the Cambrian rocks of Ireland, and are known by the name of Oldhamia, must yet be designated as *incertæ sedis:* they have been referred to several different classes by different authorities, but Mr. Salter stated his belief that one of the species was a 'gallery' of an annelid or crustacean, and Professor T. G. Bonney writes that he considers both species to be 'galleries of minute crustaceans.'

some places be penetrated by species of boring mollusca (*Pholas*, etc.) which lived during this interval. Again, it may be that the fossils of the lower bed, and of other beds formed during the intervening period, have been washed out and mixed up with those of the still more recent stratum which now rests on the eroded surface of that below. In such circumstances the basement bed of the overlying stratum often consists of a 'bone bed,' or 'nodule bed,' which is generally very rich in organic remains; indeed, the nodular lumps which usually characterise such beds mostly owe their origin to the presence of organic matter, the decomposition of which has resulted in their production. Those containing phosphate of lime or other materials of commercial value are often extensively worked; admirable opportunities are thus afforded for collecting the fauna they exhibit, both in the pits themselves and among the washed heaps of these products.

The so-called 'coprolite' pits in the neighbourhood of Cambridge form an example of this mode of occurrence. In such cases the actual collecting of specimens is a very easy matter, but the open cutting should always be visited, and it is very desirable that the derived fossils should be kept separate from those which appear to belong to the matrix of the nodule bed; otherwise the fact of the commingling of different faunas on the same horizon is likely to be overlooked. This actually happened in the case of the Cambridge Greensand, and erroneous conclusions were drawn regarding its position in the geological series and its relations to other greensands with which it appeared to be homotaxial; its true position was not recognised until it was admitted that the greater number of its fossils were derived from older beds.

Again, concretionary nodules of every kind, whether

accumulated in layers or not, should always be examined and broken open, since many excellent fossils are frequently obtained from them; such as those enclosed in the ironstone nodules of the Carboniferous series, and in the *Septaria* of many clays.

Moreover, the examination of any section cannot be regarded as complete, unless the more minute organisms are collected as well as those which are of larger size and easily distinguished at a little distance. More minute fossils are almost always to be found, but a careful scrutiny is required for their detection; it is difficult to distinguish small objects on a freshly broken surface, therefore they must be sought on the weathered faces, the eye being brought very near the surface of these, and every portion closely scanned. In this way, many minute *Mollusca*, *Brachiopods*, *Annelides*, *Polyzoa*, and even the larger *Foraminifera* may often be procured.

No fragment of a larger fossil should be thrown away until it be ascertained that none of the adherent forms of animal life are attached either to its outer or inner surface; for sometimes ten or a dozen different organisms may be counted on the surface of an old and drifted shell. All heaps of clay or marl, in any pit or brick-yard, should be similarly examined; for on such weathered heaps many fossils are often exposed to view. These might otherwise have escaped detection, being only rendered visible by the action of rain, which has cleansed them from their matrix.

Finally, we may add that it will frequently be found necessary to employ the 'silver hammer,' and to purchase fossils from workmen; but they should always

be closely questioned as to the exact part of the pit or quarry whence they obtained the specimens.

II. *Examples.*—In illustration of the previous remarks, we may refer to the diagrams, figs. 5, 6, 7, and 8, and to the descriptions of open sections which are assumed to exist therein (pp. 106—117); taking these as instances to which some of the above hints and instructions may be applied.

(*a.*) It will be remembered that the first quarry we entered, in imagination, was a sand-pit near the church, in fig. 5 (see p. 28). In the light grey sand at the bottom of this pit a few fossils were noticed, the most conspicuous being some hard pear-shaped lumps or nodules. Looking at some of these through a hand-lens, we perceive indications of organic structure, and accordingly transfer several to the fossil-bag, although at the time we may not recognise them as sponges of the genus *Siphonia.* In the harder sandstone layer a few *Pectens* and *Exogyræ* may be found; and wrapping these in paper, we write on it the following pencil note: 'Sand-pit near —— Church, bed *b.*'

The sand above yields no organic remains, but the overlying nodule-bed contains many. Some are casts in brown phosphatic matter, easily extracted from the matrix; others retain their shelly covering, and should be detached with portions of the rock; some are fragmentary, others in a fairly perfect state. We collect all the good specimens, and some of the bad ones which appear to differ slightly from the rest. Among them we recognise such forms as *Ammonites varians* and *Am. Coupei*, *Rhynchonella grasiana*, and *Rhyn. Martini*, together with species of *Ostrea*, *Pecten* and *Plicatula.*

The casts in phosphate may belong to different species, and are kept apart in separate packets. When all are stowed away in paper or chip boxes, according to their size and fragility, we write on each box or packet that the contents came from bed *d* of the note-book section.

In the marly chalk above we notice that but few fossil remains occur; we extract, however, one or two *Belemnites*, a few small *Brachiopods*, and fragments of *Inoceramus*. These, though apparently worthless, and not easily identified, are nevertheless kept, and their occurrence noted, since in other pits on the same horizon better specimens may be obtained, with which these may be compared. If we are not able to name at once the species which have thus been collected, we leave spaces in the note-book, and fill in the names after consulting palæontological authorities.

(*b*.) Passing down the road to the brickyard, which was next examined, and searching over the clay thrown aside, as well as in the vertical cutting of the pit, we find that fossils are not uncommon. They mostly retain their shells or tests in very fair condition, and only contain the dark mud in which they lie. Some, however, which we observe to occur mainly along one definite line, are filled with iron pyrites or with impure phosphate of lime, many of these being merely casts in one or other of the above minerals. From the workmen we also buy what fossils they have laid aside when digging the clay in the winter. These are generally only the larger species, while for the less conspicuous fossils we must search the pit ourselves. We may suppose that the following are entered in the note-book as

occurring here, the more doubtful forms being reserved for future identification:

Ammonites varicosus.	*Solarium ornatum.*
——— *splendens.*	*Plicatula pectenoides.*
——— *rostratus.*	*Avicula gryphæoides.*
Hamites sp.?	*Inoceramus sulcatus.*
Belemnites attenuatus.	*Rostellaria sp.?*

We also secure a few of the different forms of the phosphate nodules from the seam in which they were noticed to occur.

It is not always, however, that a clay-pit is so fossiliferous as that described above; indeed, if the workmen happen not to have any specimens on hand, little else may be obtained from such gault-pits than a few *Ammonites, Belemnites, Plicatulæ,* and phosphate nodules, though a regular seam of the last is tolerably sure to afford a more or less abundant and well-preserved fauna.

(*c.*) At the well we are not likely to obtain any fossils unless some of the clay which was extracted still remains near the mouth, or the well-sinkers happen to have kept any specimen from the beds passed through.

(*d.*) At the chalk-pit behind the farm we find that fossils are tolerably abundant in the grey sandy stone. Hammer and chisel are soon at work, and lumps of the stone are detached (see cautions on p. 217) containing *Pecten orbicularis, Plicatula inflata, Lima globosa, Ammonites varians,* and some rarer species. The workmen have a small store, which we secure 'for a consideration.' Most of the specimens thus obtained are of conspicuous size; and we do not leave the pit

without closely examining the weathered surface of the rock wherever it is accessible. This search results in the discovery of some smaller forms, such as *Kingena lima*, *Terebratulina gracilis*, *Rhynchonella Mantelliana*, *Micrabacia coronula*, etc.

(*e*.) It will be remembered that at the brickyard in the second slip of the map (p. 34), a few small shells (*Helix*, *Pupa*, *Succinea*) were found as we examined the weathered face of the loam. These are consigned to small chip boxes filled up with soft paper or sawdust. The workmen say that they sometimes come upon large bones, but some of them soon fall to pieces. We promise a reward for any small bones, or for the information when a large one may be discovered, as the removal of a large bone or skull will require our personal superintendence. In the event of such a discovery, considerable preparations will be necessary, which will be best explained by a description of what was actually done in a given case. We therefore quote the following from a note by Dr. H. Woodward in the 'Geological Magazine,' vol. ii. p. 93:

'Having been present during the exhumation of the cranium of the Mammoth (Elephas primigenius) at Ilford (described and figured in the "Geological Magazine," 1864, vol. i. p. 241), I will state the method adopted by Mr. W. Davies of the British Museum, assisted by Mr. Thorn and others. A spring van was sent down, carrying a good supply of the best plaster of Paris (1 cwt.), six pieces of ½ inch "nail bar-iron," 6 to 8 feet long, a bundle of splines, a box full of hay and tow, some strips of old canvas, whity-brown paper, two large earthen pans, in which to mix the plaster, spades, trowels, a saw, iron hammers, spatulæ, etc., good stout cord and rope, deal planks, and a hand-barrow upon which to move the remains, and some large wooden trays, in

which all the loose portions were to be systematically placed, and marked with pencil on separate papers to show the parts to which they belonged.

'You must imagine the skull resting half exposed in compact brick-earth, requiring a spade or trowel to remove it, but the fossil itself as friable as decayed wood or tinder, the ivory of the tusk being equally soft and shattered. The first operation was to remove as much of the soil as could be done with safety; the whole tusk was then covered with sheets of whity-brown paper; a coating of well-mixed plaster of Paris was placed over the paper covering the tusk, and allowed to settle down upon each side in the groves which had been scraped in the brick-earth, forming a coat of this shape ∩ over the entire length of the tusk. When the plaster had set, two bars of the iron above mentioned, which had been bent to the proper curve, were placed upon the hard plaster, and fixed to it with another coating of fresh-mixed plaster of Paris. When these coats had properly set, the base of the tusk, which had been carefully cleared and coated all round with plaster, was sawn through a few inches below the socket; the tusk was burrowed under at intervals with the trowel, and hand-holes thus made beneath it, through which were thrust strips of canvas, hay and cord, like the cerements of a mummy. When thus secured, six men turned it gently over from its matrix, and placed it on a long plank prepared for it (the curved part being supported and fixed with packing), and so transferred it to the van. The second tusk, removed a week later, was raised in a similar manner.

'The treatment of the skull was much after the same fashion, except that a coat of fine tenacious clay was used to fill up the nasal apertures and cracks. Over the first coat of plaster laths and soft iron-bars, bent to the curve, were fixed, as in the case of the tusk, to give rigidity to the whole. As the matrix was removed, pieces of wood were packed under with soft hay to support the head, which, being filled with brick-earth, was very heavy. When quite cleared and secured, it was turned gently over upon a soft bed of hay placed on the hand-barrow ready to receive it. The zygomatic arch invariably falls away

from the cranium, dividing at its sutures; the pieces should always be sought for in the matrix beneath, and taken especial care of. The labour and care necessary are immense, but I feel sure that almost any similar fossil remain might thus be secured, provided always the same amount of skill and patience be brought to bear upon the brittle mass.'

(*f.*) The fossils found here are similar to those in *e*, and the method of procedure does not differ from that just described, but the bones in the gravel are not so tender or so well preserved as those in the loam; single teeth and drifted bones are more likely to be found in this kind of material.

(*g.*) The chalk-pit in the third slip of the map has been mentioned at p. 37, and as the fossils found here are more or less similar to those we shall notice subsequently in quarry *k*, only a few special points need now be mentioned. Gasteropods and corals occur in the hard crystalline chalk in the state of casts (like that figured in Lyell's 'Students' Elements of Geology,' first edition, p. 43), the shell having been entirely removed; the external impression is kept as well as the internal cast, in order that an artificial plaster cast may be taken from the former. Ventriculites and other sponges are met with, and, except when silicified, are very friable, and require careful manipulation.

(*h* and *i.*) The fossils found at these places are similar to those occurring in the brickyard described below.

(*k.*) Brick-yard and Lime-kiln. The upper part of this section is first examined, and in the basement bed

of the Tertiaries overlying the Chalk we find some fragments of *Ostrea Bellovacina*. In the loam and sands above better specimens of the same *Ostrea* are found with *Cyrena cordata, C. cuneiformis, Melania inquinata*, and others, in a friable condition, so that packing is required. The solution of an important question may depend on the fossils' evidence, *i.e.*, whether the beds belong to the Thanet Sands or to the Reading series: the discovery of the above-mentioned shells decides the question in favour of the latter group; if, however, *Cyprina Morrisii, Panopæa granulata*, and a *Pholadomya* had been met with in the lowest bed of sand, the discovery would have led us to conclude that they were the more ancient Thanet Sands.

The deep excavation in the Chalk is next examined. Some speak of the main mass of the Chalk as so sparsely fossiliferous as to be rarely worth examining; but this impression is due to the fact that fossils are not so easily detected in the Middle and Upper Chalk as in most other Secondary rocks; the organic remains being nearly of the same colour as the rock itself, looking closely at which is very trying to the eyes, on account of its dazzling whiteness. We first turn our attention to the flint-bands, and by examining the nodules in place, as well as the heaps of those which we see by their white exterior to have been in place, we soon collect several Echinoderms: *Ananchytes, Galerites, Micraster*, and a few specimens of *Inoceramus* and *Spondylus*, all imbedded in the flint. These must be trimmed as well as possible, although flint is intractable and as likely to split through the fossil as along the plane intended. Flint is perhaps best manipulated by holding the lump

in the left hand, and chipping it by well-aimed blows of the hammer, directed away from the fossil.

The flints having been well looked over, we turn to the beds of chalk, and when our eyes become used to its appearance we soon extract, by means of hammer and chisel, specimens of the same species just found, with the addition, perhaps, of some smaller fossils, such as *Magas pumilus*, *Terebratula carnea*, *Rhynchonella octoplicata*, spines of *Cidaris sceptrifera*, and stems of *Bourgeticrinus*. We examine also the tests of the large and smooth Echinoderms, such as *Ananchytes* and *Galerites*, which are often the resting-places of *Crania*, *Plicatula*, and the minute *Thecidium Wetherellii*, as well as various species of elegant *Polyzoa* and *Serpulæ*.

(*l.*) In the pit by the W. corner of the wood (slip 4), we do not find a great variety of fossils; it has been noticed that a particular kind of oyster is generally abundant in the marly bands at this horizon, besides this some *Rhynchonellæ*, *Terebratulæ*, and *Fish-teeth* may reward our search in these layers, with perhaps a specimen of the Belemnite (*B. plenus*), which is specially characteristic of this part of the Chalk.

Passing now to the Palæozoic area (p. 73 *et seq.*) we find that a study of the fossil evidence is still more necessary to confirm the conclusions drawn from the survey of the rocks. The geological structure of the area previously described is comparatively simple, but in more complicated cases, where the stratigraphical relations are less easily disentangled, the practical value of palæontology is proportionally enhanced.

In drawing the boundary between the Silurian and Carboniferous rocks west of Walsall, the Wenlock shales were found abutting against the shales and sandstones of the Coal-Measures; the shales of the two formations do not greatly differ, but their fossils are very different, therefore the discovery of fossil remains near the junction of the two rock-groups will assist in determining the line of boundary; similar evidence would serve to confirm the line of fault drawn between the same beds south of Walsall.

The fossils found in the limestone quarries north of Walsall (p. 81) demonstrate that the beds seen there belong to the Wenlock or Dudley series; the corals, shells, and trilobites being such as are mentioned under that head in the list on p. 281. The occurrence of similar fossils in the railway cutting shows that the limestone there exposed belongs to the upper band of the same series. The ground east of Walsall does not afford any exposures from which fossils could be collected, but when the canal was in process of construction the cuttings yielded many excellent specimens of the Brachiopods and Echinoderms characteristic of the Wenlock shales. From the Limeworks near the Three Crowns Inn, a basket full of fossils may easily be obtained, the best specimens being those weathered out of the hard matrix by long exposure on the floor of the quarry. No difficulty will be found in collecting the fossils in these cases, if attention be paid to the directions already given. As regards the evidence afforded by them, the Walsall limestone having once been identified by its fossils, the palæontology of the other rocks confirms the conclusion arrived at on stratigraphical grounds.

The fossils of the sandstone quarry (Note *q.*) are more important, for the area of its exposure is so small that little can be ascertained from a survey of the ground except that it appears to emerge from below the Wenlock rocks. Although this position would at once suggest its belonging to the next term in the descending series, *viz.*, the May Hill Sandstone, yet it is possible that there might be an unconformity between it and the overlying shales, so that the sandstone might belong to a still older period. Or the boundary line might be a down-throw fault, and the sandstone might belong to the Carboniferous series just as the Coal-Measures are actually brought down, so as to occupy a similar position between the Silurian and the Permian beds a little northward of this locality. The character of the sandstone would doubtless afford some evidence, but no real proof would be forthcoming until the fossils which it yielded had been identified. The following is a list of the species found when this locality was first explored and described.

Trilobita -	*Encrinurus punctatus.* *Phacops caudatus*, and others.
Mollusca -	*Pentamerus liratus.* *Strophomena compressa.* *Atrypa reticularis.* *Rhynchonella Wilsoni*, and others. *Acroculia haliotis.*
Crinoidea - -	*Periechocrinus moniliformis.*
Actinozoa -	*Petraia bina.* *Favosites alveolaris.*

These are sufficient to identify the rock as belonging to the May Hill Sandstone or Upper Llandovery.

(*n.*) Round the mouth of the coal-mine, mentioned

at p. 116, there are scattered portions of the various measures passed through in sinking the shaft; among the fragments of sandstone and fire-clay thus brought to light we may find remains of *Calamites*, *Stigmaria*, and *Sigillaria;* in the shales and shaly sandstones we detect impressions of *Lepidodendron* stems, together with the broken fronds of *Neuropteris*, *Sphenopteris*, and other ferns, all black and carbonised. In the dark shales also Unio-like shells occur, belonging to the genera *Anthracosia* and *Anthracoptera*, but they are often more or less crushed; the best specimens are obtained from the dark-grey ironstone nodules which are scattered about, and which we ascertain to have been derived from the measures below the 'Fire-clay Coal.' Besides the bivalve shells, these nodules contain beautiful fragments of fern leaves, as well as *Lepidostrobi*, or the cones of the *Lepidodendron*, and sometimes the scales or coprolites of fish; it was indeed the decomposition of the animal or vegetable matter that determined their formation.

This assemblage of organic remains affords clear evidence of the conditions under which the strata were deposited. They are such as would flourish in marshy and swampy ground near the debouchure of some large river, they speak of great inundations and successive submergences of the low-lying land-surface, on which the materials that form the coal seams were gradually accumulated.

Now, descending the pit, we explore some of the main passages, or gate-roads, under the guidance of the foreman, or 'butty-collier;' in some places we find the roof above us to be crowded with splendid impressions

of ferns and other plants, the shales immediately above the coal being often extremely rich in such remains; and we thence obtain more perfect specimens than we could at the mouth of the pit, with the additional advantage of knowing the precise horizon in which they occur.

In some coal-fields thin beds of limestone are occasionally found intercalated among the other measures, and any such band that may be observed should be carefully examined, for the fossils found therein are usually marine forms, and are interesting as proving the temporary occupation of the palustrine area by the waters of the neighbouring sea or estuary. In the colliery above described, however, no such beds were met with, but pieces of shale and limestone with Silurian fossils were picked up on the banks outside, and the section on p. 116 shows that the shaft was carried completely through the Coal-Measures far into the Silurian rocks beneath. That this needless expense should have been incurred exemplifies the truth of the remarks made on a future page (p. 263); it was impossible to find coal beneath beds containing Silurian fossils, of which great numbers, like those in the shales and limestones near Walsall, must have been brought up from these workings and must have been silent witnesses of the futility of the undertaking.

CHAPTER III.

THE PREPARATION OF FOSSILS FOR SCIENTIFIC USE.

Importance of fixing locality—Cleaning and Preserving specimens—Selecting and Cataloguing of Fossils—Nomenclature and Species—Making Arrangement and Labelling.

Preliminary Remarks.—We will now suppose that the collection of fossils has arrived at its ultimate resting-place, whether that be a private or a public museum; in the latter case, the geologist is saved further time and trouble by the palæontologist or the curator and his assistants, who undertake the future treatment of the specimens. A few hints, however, may be useful to those who have to perform the processes for themselves; and the first point to be attended to is that the fossils from different localities do not get mixed as they are being unpacked. When the time comes for this, the memory should be trusted as little as possible; even slips from the margin of a sheet of postage stamps will often serve a temporary purpose, or marks may be scratched on the matrix of the specimen.

Hints for cleaning and preserving.—Steps must next be taken to clean and preserve the more delicate specimens, and to prepare them for the handling that is afterwards necessary. The removal of the matrix is

often a difficult operation, requiring much care and patience. Fossils from the older and harder rocks are frequently spoilt by hasty attempts in this direction, for it is seldom that such fossils can be at once completely extracted from the matrix; they will either have to be left much as they were when first disclosed by the blow of the hammer, or they may be exposed to the action of the air, rain, and frost, so as to become artificially weathered and loosened from the parent rock. Even when the rock is soft enough to be cut with a knife, the fossil is often too tender to be entirely removed; it must, therefore, be left in the matrix, as much of the latter being removed as circumstances will allow.

Specimens that have been cut out of soft clays, or argillaceous sands, like the Gault or Bracklesham beds, are apt to crumble in drying; these, therefore, will be benefited by being soaked in some preservative solution. For this purpose gum-arabic or gum-tragacanth mucilage, or a mixture of diamond cement and water, will be found useful, and may be applied by means of a soft brush, after the specimen has been trimmed and cleaned.

Fossils that have been obtained from the Chalk or any similar porous limestone along the sea-shore should be soaked in fresh water for several weeks, the water being changed at least once a week; this prevents the efflorescence of the salt in such cases, and the consequent splitting up of fossils which have cost time and pains to extract.

In cleaning chalk fossils great care should be taken not to scratch or scrape the surface of the shell or test. The enclosing chalk should be softened in fresh water,

and may then be nearly cut away with a knife, but the remnant of the matrix must be removed by a brush of some kind, and the sooner such fossils are cleaned the better, as the chalk is apt to become dry and hardened, and difficult to remove.

Fossils which have been obtained from loose sands and gravels will require thorough soaking in a solution of gum or gelatine. For the molluscan remains and other fossils of small size, it is best to use a weak solution of gelatine, of strength sufficient to set into a weak jelly on cooling. It should be made in a shallow vessel and be used while still hot, the objects being lowered into it on a piece of perforated wire gauze, or some other kind of strainer; if, however, the shells are exceptionally delicate, the solution must be ladled on to them, and this operation may have to be repeated a second time. In dealing with the remains of Vertebrata, a similar treatment should be adopted; varied, of course, according to the necessities of each case.

In this matter Mr. W. Davies, of the British Museum, has had great experience, and we quote the instructions which he has given.*

'The substances generally used are glue or gelatine. For the bones of the larger mammalia, there is nothing better than the best glue; whilst for the more delicate bones of the smaller mammals, birds, and fishes, gelatine is the best, being purer, dissolving more easily, and imparting little, if any, colour to the fossil. The consistency of these substances when used will have to be varied according to the structure of the bones, and this must be left to the judgment of the operator. As a general rule, however, all bones which have a coarse cellular structure require the glue solution to be of a consistency which will form

* 'Geological Magazine,' vol. ii. p. 239.

a stiff jelly when cold; whilst for bones of a compact structure a much thinner solution will suffice. If the solution is too thick it clogs the absorbing power at the surface, and prevents its penetrating to all parts of the bone. The fossils should be thoroughly dried and cleaned from as much of the matrix as can be removed with safety; and if it can be managed warmed before being placed in the solution. When the glue is all dissolved and the liquid nearly at boiling heat (ebullition should be avoided, if possible), it is ready for the immersion of the fossils, and they should remain in it as long as air-bubbles rise to the surface; when these cease they will be sufficiently soaked. When taken out they should not be drained, but laid in a position to retain as much as possible of the imbibed solution until they are cold, when the glue will have set. Their position must then be shifted, to prevent their adhering to the board on which they may be laid. Any glue that may have drained from them may be then removed with a wet sponge. The vessels required are of the simplest kind: the ordinary saucepan, or better still, a large-sized fish-kettle with its strainer. But whatever the vessel used, a strainer of some kind, on which to place the bones for immersion or withdrawal, is indispensable. . . . For long limb-bones strong enough to bear their own weight when saturated, it is only necessary to place one end in the vessel and ladle the solution over the other end for a short time, and then reverse their position. But for bones which will not bear such treatment, the only plan is to fix them securely to a board, and place them in a slanting position in the solution, and well saturate them with it by ladling. . . . Occasionally fossils are found which are either too large or too friable to be placed in the solution; for these a different method must be adopted to preserve them entire. Cover the fossil with thin paper, over which—on the sides and underneath, if possible—put a coating of plaster of Paris just thick and strong enough to keep together; when firmly set gently pour the solution boiling hot over the fossil as long as it continues to absorb, to assist which it may be necessary to remove in a few places some of the surface bone, which can be carefully replaced; in two or three days the plaster may be partly removed by sawing, and in small

pieces, taking care not to injure the fossil by jarring it; the paper will prevent the plaster adhering to it. But this process is never so effective as submersion in the solution, and may require to be repeated.

For cementing large pieces of bone together, Sir Antonio Brady recommends strong glue mixed with a small portion of fresh burnt plaster of Paris; but for smaller bones, shellac dissolved in naphtha is said to answer best.

During these processes, a few of the more worthless duplicates from the same bed and place may perhaps be thrown away; when the whole collection has been finally prepared for examination, every specimen should be numbered and catalogued before selection is made or any attempt to identify them is commenced. But whatever temporary method has been adopted for retaining the clue of locality, *it is of the utmost importance that it should in some way be permanently registered on every specimen*; each should bear some mark to indicate the place where it was found. Letters or numbers may be inked or painted on the matrix, or some adhesive label may be affixed to the fossil itself; the particulars should be entered in a special book, the locality and 'location' of the fossil being clearly indicated.

Names and Nomenclature.—If it is possible to retain the services of a professed palæontologist, the whole collection is now put into his hands, and from him the field geologist obtains a full account of the fossils procured during the exploration of a given area or country.

Every geologist should however be more or less of a palæontologist himself, and a few suggestions will therefore be given for the furtherance of private work in that department, and in this connection a few points will be

noticed which seem to demand the attention of all workers in palæontology. The books and monographs in which fossils have been figured and described are often large and expensive, consequently it is generally necessary to have access to a library whence the necessary books of reference may be obtained. In England, France, or Germany, some or all of the following works will have to be consulted.

The Publications of the Palæontographical Society, in which 4000 species of British fossils have already been figured and described.

Decades of the Geological Survey of England.

McCoy's *Palæozoic Fossils*, published by Prof. Sedgwick.

Sowerby's *Mineral Conchology.*

Mantell's *Medals of Creation.*

Owen's *Palæontology* and Nicholson's *Manual of Palæontology* will also be found useful.

Baily's *Figures of Characteristic British Fossils.*

D'Orbigny's *Paléontologie Française.*

Pictet's *Matériaux pour la Paléontologie Suisse.*

For the fossils of particular formations, such works as Dixon's 'Geology of Sussex,' Murchison's 'Siluria,' Ramsay's 'North Wales,' and other Survey Memoirs must be consulted, as well as papers in the Publications of the Geological Societies of London and Paris.

In identifying species by means of these volumes we shall probably find some which are apparently intermediate in their characters between two allied forms, and are thus difficult of determination, since they might belong to either of the figured species; others, again, may vary more or less from the particular type which

happens to be figured. It is often the practice in such cases to put these aside for duplicates, or to throw them away, only inserting in the collection what are termed 'typical specimens;' but this mode of procedure is highly reprehensible, since it tends to confirm the old notion that species are definite abstractions, and separate cognate forms by hard and fast lines, while in reality they are bound together by many intermediate links. These forms ought, on the contrary, to be placed with the species to which they are allied, and to be labelled as a variety of that which they most closely resemble; and it should be the aim of the curator to exhibit all such varieties and not those only which have been stereotyped as typical forms. Had this always been done we should now be in possession of many more facts than we possess regarding the life-history of such species; for varieties indicate steps in the gradual evolution of species, and it will frequently be found that such intermediate forms have been collected from intermediate beds, one of the allied species being mainly found above, and the other below, the horizon in which such middle varieties occur. Here therefore is a fruitful field where much interesting work remains to be done, and which may result in profit and advantage to biological science.

The following sentences from the pen of the late Professor Phillips further indicate this line of research:* 'In a limited sea basin, in one system of strata, deposited under similar conditions, with continuous life, the distinctive forms of the several genera ranged in order of time furnish evidence, the most complete we are ever likely to obtain, whereby the hypo-

* 'Geology of Oxford,' etc., p. 400.

theses referred to can be examined, or rather one of them, that of "descent with modification." Sedentary races (such as *Brachiopoda* and *Conchifera*) rather than erratic ones should be chosen to prosecute this inquiry.'

Besides these somewhat indeterminable forms, we may also discover some that do not appear to be figured or described in any of the books we can consult; these should be put aside, and if possible shown to some palæontologist who makes a special study of the groups to which they severally belong: should they prove to be entirely new species or definite varieties, they may be described as such when an account of the district comes to be written. The description of new species, however, is a matter which should be undertaken with the greatest deliberation. Every science has become burdened with such a multiplicity of synonyms, and the nomenclature in many cases is so unsatisfactory, that the student is perplexed with the labyrinthine difficulty of the subject. To discuss this question fully would be beyond our present purpose, but we may briefly point out the main causes of this unsatisfactory state of things, and suggest some means of remedy.

In the first place, the illusory ideas regarding the definiteness of species have greatly contributed to it, for different authorities have had different estimates of specific differences, and many so-called species are after all mere arbitrary creations of individual opinion. Secondly, there exists the great desire of finding something new to Science, and of being the first to describe it, which too often takes the form of 'species-making' instead of discovery. Thirdly, there is the difficulty of

finding out whether a species has been previously described, either by British or foreign writers; a most fruitful source of the multiplication of synonyms.

The first opens up that difficult question—what constitutes a species? Without venturing to frame anything like an accurate definition of the term, we apprehend that certain postulates may be deduced from the results arrived at by Dr. Darwin and Mr. A. R. Wallace. We are told that genera, species, and varieties differ only in degree; they may therefore be described in common terms, and a genus, species or variety may each be viewed as an assemblage of individuals possessing in common certain characters which do not exist together in any other similar assemblage. But the three differ in degree, since there are more resemblances between different varieties than there are between different species, and again there are more resemblances between different species than between different genera.

Varieties may thus be regarded as assemblages between which the differences are not so great as to prevent our seeing that they may all have been derived from one parent stock. They are therefore all referable to one specific group. Species are assemblages between which the differences are greater, the divergences being produced by certain influences, the operation of which has been designated 'Natural Selection;' the process of their evolution is therefore less easily perceived; still they are referable to one group or genus. Genera are assemblages between which still greater differences have been produced by the further operation of the same causes, the introduction of new diversities and the extinction of intermediate species having left great gaps in the

chain of existence. Thus genera may be traced back to species, and species have once existed as varieties.

Dr. Darwin looks forward to a considerable revolution in natural history.* 'Systematists,' he says, 'will not be incessantly haunted by the shadowy doubt whether this or that form be a true species. They will only have to decide (not that this will be easy) whether any form be sufficiently constant and distinct from other forms as to be capable of definition; and, if definable, whether the differences be sufficiently important to deserve a [varietal or] specific name. This latter point will become a far more essential consideration than it is at present; for differences, however slight, between any two forms, if not blended by intermediate gradations, are looked at by most naturalists as sufficient to raise both forms to the rank of species.'

It must be admitted that a name is required even for varieties when these are definite and constant; thus the only way out of the difficulty appears to be in the more general use of varietal names (appended to specific names), and of sub-generic titles, so that a *trinomial* instead of a *binomial* nomenclature will have to be used. Varieties must be grouped under species, and species must be grouped together under genera; many of the forms now occupying the place of species must be viewed as varieties, synonyms may sometimes be revived as varietal names, while new forms should be described as varieties if they can possibly be affiliated to any other previously known and properly described species.

With regard to the second tendency, mentioned above, it has often happened that a discoverer has hastened to vindicate his claim to priority by describing

* 'Origin of Species,' 6th edition, p. 425.

the specimen before he has taken sufficient pains to establish the fact of its being a new species. Imperfect fragments, inconstant varieties, monstrosities, and aberrant forms, have in this way been floated as species, and have subsequently occasioned the expenditure of much time and trouble on the part of more cautious workers, for it is far easier to give a new specific name to an object than to disprove its title to the same.

Commenting on this practice of 'manufacturing' new species, Dr. Carpenter truly observes, 'It should be borne in mind that every one who thus makes a bad species is really doing a serious detriment to science; whilst every one who proves the identity of species previously accounted distinct, is contributing towards its simplification, and is, therefore, one of its truest benefactors.'

The last and most direct cause of the multiplication of synonyms is only to be avoided by greater industry in research, and by fuller acquaintance with the work already done.

In the endeavour to ascertain whether any given form has been described, or its proposed name previously applied, the following works will be found of great service: 'Bronn's Palæontological Index;' 'Morris's Catalogue of British Fossils;' 'The Thesaurus Siluricus,' and 'Thesaurus Devonio-Carbonicus,' of Dr. Bigsby; Miller's 'Catalogue of American Palæozoic Fossils.' Geologists will also derive assistance from the annual appearance of the 'Geological Record,' which aims at giving a brief notice of every book, pamphlet, or paper, published at home or abroad on any geological subject. The first volume was issued for 1874, and it is to be regretted that it had not an earlier commencement.

It will be seen that the institution of a new species requires the possession of much previous knowledge, and the exercise of patience and care; but one of the

difficulties which the describer will encounter has been only incidentally mentioned, viz.: that of framing a new name for the object he has discovered. This may seem an easy task, but the difficulty is soon felt by any one who endeavours to frame a good distinctive appellation. It has been well said that 'a short, well-sounding, appropriate name for a new object is as clever an achievement as a good proverb, or a neat epigram, and is rare accordingly.' Some evade the difficulty by using the Latinized name of a personal friend, or some well-known man, supposed to be complimented thereby; but this nomenclature is barely pardonable, even in the form of a generic designation, and is altogether objectionable when applied to a specific name. It is to be hoped that the practice may soon be abandoned, and condemned by a general consensus of scientific opinion. Indeed, some sort of censorship might well be exercised by scientific societies over the new names that are given to the world under their auspices. In the construction of new names, whether generic or specific, the following points should be attended to: (1) the rules of classical composition should always be regarded; (2) the names should not be awkwardly long, but should be as neat, short and pithy as possible; (3) generic names should rarely be compound, but are best formed from some simple substantive or adjective, *e.g.*, *Conus*, *Cardium*, *Solen*; (4) specific names should always convey some idea suggested by one of the distinctive specific characters.

The late Dr. Page has some excellent observations on the subject of 'Species-making and Nomenclature' in his 'Chips and Chapters for Geologists,' and we obtained his permission to quote the following paragraphs. Speaking of the censure

which Dr. Hooker has passed upon the students of Fossil Botany, he says :

'This is a grave charge, indeed, and yet it must be confessed that it is too true, both as regards the temerity to give names to unintelligible fragments, and the principles of the nomenclature itself. Carbonised and coaly fragments of stem, branch or leaf, are yearly erected into genera and species ; roots, stems, and leaves of the same plant often receive different *generic* titles, and legible fragments of well-known genera have as regularly conferred upon them new specific designations because of some accidental variation. Thus it is that the science of Fossil Botany is cumbered with unnecessary genera, while the specific names convey no information whatever, either as to appearance, structure, or affinity. The term *Whitbiensis*, for instance, conveys no botanical information, and even misleads, when the same fragments are known to be found in Dorsetshire ;* while the designations *Brownii*, *Jonesi*, and *Robinsoni* (often after men totally unknown to science), are simply worse than ridiculous.

'Nor is the matter one whit better when we come to examine the practice in Palæontology proper, or Fossil Zoology. The slightest variation in form is sufficient for a *Smithii* or *Brownii* being added to the list of species ; while a greater variation is almost certain to lead to the establishment of another genus. Three forms of palatal teeth, for instance, are discovered in the Carboniferous system, and each receives a generic name ; a few years of research pass by, and all three forms are found to belong to the same mouth. Two forms of fin-spines are detected in the Old Red Sandstone, and each receives generic distinction even from an Agassiz ; several years pass by, and a single fish is discovered possessing the two spines—one form for the pectorals, and another for the dorsals ! Scales with slightly different

* In the case of varieties, however, when it is often difficult to seize upon any prominent distinction, or to express it briefly in the compass of a name, we hold it excusable to call the new varietal form after the locality where it was found, and in the neighbourhood of which it is probably most abundant.

ornamentation are dignified with specific titles ; and yet, when a perfect fish is secured, these scales are found to be merely variations on different parts of the same body ! Such are the evils that arise from giving names to imperfect fragments; such is the worthlessness of hundreds of provisional designations arising from the vain desire to be foremost in the race of priority. Taken by themselves, a few specimens of certain shells may appear to warrant a specific designation ; but when a large assemblage of these shells has been brought together, the graduation of one form into another is so imperceptible, and the whole so similar to some established species, that the propriety of regarding them merely as varieties of that species can no longer be questioned. And it is simply for want of this careful and sufficiently extensive comparison that species are manufactured out of the most trifling differences, and that our fossil lists are encumbered with factitious and questionable distinctions. Age, sex, individual condition, and the like, make wonderful differences in living species, and yet such circumstances are seldom taken into account in the discrimination of those that are fossil. And even when the species is good, the name has often no reference whatever to the distinction, being altogether meaningless and absurd. Such terms as *striatus*, *reticulatus*, *falcatus*, and the like have a meaning, and convey the distinction to which they refer ; but *Cornubicus* or *Jamesii* has no significance at all, or, if it has, it is a misleading one, as the organism may be found in other districts than Cornwall, and James may have had no hand whatever in the discovery of the species to which he stands godfather. In deprecating this system, or rather non-system, of indiscriminate species-making and meaningless nomenclature, we are by no means arguing against the value of scientific names and technical distinctions. New objects must have new names, and new facts new phrases, to express their relations. We are not even undervaluing the advantage of provisional terms and temporary distinctions. What we object to is the absurdity of conferring specific names on minute and, it may be, mere accidental variations ; of giving generic and specific names to obscure fragments till further discovery has revealed fuller and clearer information ; of applying

meaningless instead of descriptive and significant terms, and of thus cumbering the science with names instead of realities. No student who values the purity and progress of his special science can possibly defend the practice at present followed; and the best way in which he can assist in counteracting its tendency is by carefully and resolutely adopting for his own discoveries a strictly descriptive nomenclature, and by as cautiously refraining from conferring generic appellations on obscure fragments which the discoveries of another day may show to belong to something already determined.'

Arrangement of Collections.—We have often been questioned as to the best mode of displaying and arranging fossils. With regard to the mode of arrangement, whether according to their place in the succession of life or of strata, there can be only one answer: the latter is always preferable for geological purposes, however much the former may commend itself to the pure biologist. Nevertheless, in collections of any size, it is always possible to have zoological arrangement, by placing together those of the same natural group and class, and pursuing the same order of classes throughout all the formations.

Regarding the method of displaying the fossils:—In museums, where the collections are supposed to be perfected, and to remain for many years as arranged, the specimens are generally fastened down on tablets; but in private collections, used for constant reference, and to which frequent additions are made, such a plan is attended with many disadvantages. A better way is to place them in small card-board trays, made of multiple sizes like the tablets. Every fossil may then be fully examined, while the labour expended in gumming them down is avoided, and the additional advantage of space is gained at the same time.

Where tablets are used, labels bearing the name, locality, etc., can be gummed on to them; but if the fossils are left loose in trays, a label or some record of 'locality' must be attached to each individual specimen, so that the clue to this important particular may not be lost in any subsequent re-arrangement (see p. 240). Small adhesive labels will be found well fitted for this purpose, and different sizes may be obtained. In the case of many specimens from one locality, the plan we adopt is to label two or three fully, and to mark the locality or its initial letter on all the others, either writing on the fossil itself, or on a small label gummed on to it. Fossils which are too small to be labelled are best kept in pill-boxes, on the top of which full particulars can be written.

To the stratigraphical geologist a fossil without any memorandum of locality is absolutely useless. Hundreds of otherwise good specimens have been rejected in arranging museum collections because no one had preserved any record of the place where they had been found. On the other hand, the mere initials of a locality have saved many a fossil from being thrown away.

The value of field-work is much greater when due attention has been paid to the collection of fossils, and the establishment of more concerted action between observers in the field and workers in the museum, is greatly to be desired.

CHAPTER IV.

NATURE AND VALUE OF PALÆONTOLOGICAL EVIDENCE.

Evidence of Physical Conditions—Characteristic Fossils—Strata identified by Fossils—Synchronism and Homotaxis—Palæontological Zones—Practical Use of Palæontology—Conclusions.

HAVING now explained the method in which the fauna and flora of a district should be collected and worked out, we are in a position to estimate the full importance of the information thus obtained: in the light of such knowledge we can often ascertain the physical conditions under which any bed or group of beds was formed, and can decide questions regarding the relative age of the rocks. The insight afforded by Palæontology into these subjects was briefly pointed out at the commencement of Chapter I., but may now be more fully explained.

Evidence of Physical Conditions.—First, as regards the various conditions under which rocks may have been formed, our knowledge is chiefly derived from the evidence furnished by the organic remains they contain; it is clear that the terrestrial, fluviatile, lacustrine, estuarine, or marine origin of the fossils may generally be ascertained by a comparison with the habits of the

living species belonging to the same or nearly allied genera.

The remains of *Corals* and *Echinoderms* at once stamp the deposit containing them as a marine formation. Among Molluscs, the Cephalopoda, Brachiopoda, Pteropoda, and nearly all those Gasteropods which have the outer lip notched or produced into an anterior canal, are marine forms of life, and their presence is therefore a sure guide. A mixture of forms resembling recent land and freshwater shells (most of which have entire mouths) will suggest a fluviatile or lacustrine origin for the deposit, and the occurrence of insect or plant remains will render this tolerably certain. Estuarine beds will contain such bivalves as *Ostrea* and *Cyrena*, and such univalves as *Potamides*, *Melania*, and *Melanopsis*; but in a series of such beds some layers will probably contain species that are more exclusively marine (*Natica*, *Fusus*, *Corbula*, etc.); while in others the assemblage will have a freshwater facies, with *Lymnæa*, *Planorbis*, *Paludina*, *Unio*, etc., according as the waters of the sea or the river occupied the area in question.

How such alternations are produced must be learnt from Lyell's 'Principles of Geology' (see also the 'Students' Elements of Geology,' 1st edn. p. 35); but, as an illustration of the way in which the history of natural events can be read by an expert in the records of the rocks, we quote the following from the pen of Professor E. Forbes.* He is treating of the Lower Greensand in the Isle of Wight, and says:

'At the close of the deposition of the Wealden there appears to have been a sudden depression of the bed of the great freshwater estuary, and an influx of the sea. The first effect of such

* 'Quarterly Journal Geological Society,' vol. i.

an influx would be the destruction of the animals in the estuary not adapted for living in salt-water: hence we find a total destruction of the Wealden animals, the remains of which accumulate towards the point of the junction of that formation with the Lower Greensand—a fact which indicates the nature of the change. Even the *Cerithium,* though belonging to a genus many species of which are capable of living in the depths of the sea, was destroyed, notwithstanding that its appearance only in uppermost beds of the Wealden indicates that its presence there was due to the commencement of the very state of things which eventually destroyed it. That the depression was of some extent, though not perhaps of very many fathoms, is indicated by the nature of the animals which lived in the first formed sea-bed, and which, when they died, were often imbedded in the fine and probably fast-depositing mud in the vertical position in which it is the habit of animals of such genera as *Pinna* and *Panopæa* to assume when alive. After this a temporary change followed, when an influx of sand, mingling with the calcareous mud, caused a state of sea-bottom peculiarly favourable to the presence of animal life. In this way were called into existence a multitude of species, which were added to those which had appeared before. This was, in fact, such a state of sea-bottom as is now presented by great shell-banks; but it does not seem to have lasted long, and new depositions of mud appear to have extinguished some forms, whilst others suffered by the change only in the diminution of their numbers. . . . At the close of the deposition of this great mass of clay, there was, for a time, a great multiplication of the individuals of certain *Brachiopoda,* which had commenced their existence in the lowest beds. Thus *Rhynchonella Gibbsii* suddenly appear in immense abundance, covering the bottom of the sea, and predominating over the animals among which it had previously been but thinly scattered.'

But we may go farther than this, and even obtain some idea of the probable climate of past periods. When we find in certain beds the bones of crocodiles, snakes,

and turtles, together with palm-fruits and remains of other plants which now live only in tropical regions, we are forced to believe that the climate of the British islands must then have had a more tropical character. Again, when in more recent deposits we discover remains of the reindeer, musk-ox, and mammoth, and in other beds of the same age certain species of mollusca which now only inhabit the seas of more northern regions, we have good evidence for concluding that the climate of Britain was then very much colder than it is at present.

From a consideration of the character and abundance of the fossil remains we may sometimes gain an idea of the time that elapsed during their accumulation. The formation of a bed of limestone crowded with organisms of various kinds, many of the corals and crinoids being still in their upright position of growth and surrounded by the broken debris of others, together with the shells of numerous species of mollusca,—the formation of such a bed must have occupied a long series of years. On the other hand, in a bed of sand or sandstone, fossils are generally far less numerous, and among those that do occur bivalve shells will predominate; Brachiopods, Corals and Echinoderms will be rare or absent, Gasteropods may or may not be abundant. Should we find many Lamellibranchs, with separated valves, a few Gasteropods, some fragments of drifted wood, and a few bones of some terrestrial animal; such remains would indicate the rapid accumulation of the materials composing the stratum, which indeed, although of the same thickness, may only have occupied in its formation as many weeks as the bed of limestone did years.

Other facts are also elicited by such a comparison; for many of the fossils occurring in the limestone belong to genera which exist only in deep water, and the very mode in which they occur shows that the water above was still and quiet; we conclude, therefore, that it was deposited at the bottom of a deep and quiet sea. In the sandstone, on the contrary, the presence of terrestrial remains and the drifted and waterworn condition of the other fossils found therein plainly indicate their connection with a shallow sea, the action of currents, and the neighbourhood of land. Again, such indications as sun-cracks and the impressions of rain-drops tell us of parching heat, of passing showers, and even show us the direction from which the wind blew in those old days of the earth's history.

We will turn now from such evidence of the surrounding conditions at the time when the beds were formed, and approach the more difficult questions connected with the comparative age of the different beds which are found in different localities. It has been observed, that every group of strata in the geological series, and frequently even the minor beds composing the several formations, have each their own peculiar assemblage of fossils; it often happens that a particular species, or an assemblage of species, are only found in a particular bed or stratum, or if found at all elsewhere it is so rarely in comparison with their abundance in this particular stratum, that they still merit the name of *characteristic species.* Still more is it the case when a thick series of beds is examined, for such a formation invariably contains a considerable number of species

which are absolutely peculiar to it, and are never found in the rocks above or below.

This generalisation, first made by Dr. William Smith, led him to promulgate the doctrine that 'strata may be identified by their fossil contents,' and the facts, as they are now established, may be embodied in the following propositions :

1. *The entire series of stratified rocks can be divided into systems or periods, each of which is characterised by an assemblage of fossils peculiar to itself.*
2. *Each assemblage of fossil animals and plants has a greater resemblance to the assemblage in the rocks immediately above or below it, than it has to any other assemblage in the series.*
3. *The successive assemblages have a progressive character, the oldest being very different from that which now inhabits the globe, but those of the succeeding periods gradually approximating to the present fauna and flora.*

These propositions form the basis on which the science of Palæontology is built, and a little consideration will show the student that a knowledge of the fossil forms, composing the successive assemblages, must afford a method of establishing the relative age of any group of fossiliferous rocks. Even if a new formation is found, containing an entirely new assemblage of species, its position in the great series of deposits can at once be determined, for the new species would mostly belong to genera which are known to be characteristic of a certain period in the earth's history. To take a simple

instance: Ammonite shells and the bones of an Ichthyosaurus have been discovered in some of the Arctic Islands, and we at once conclude that the rocks containing them belong to some member of the Secondary system; moreover, we guess that they belong to the Jurassic formation, since the Ammonite more resembles an Oolitic form than any known in Cretaceous rocks.

Another more detailed instance may be given to show how useful a knowledge of characteristic fossils is to the geological surveyor. He might be mapping a country composed of Cambrian and Silurian rocks, and in a district where the beds were particularly disturbed and faulted, he might discover a limestone quarry. Now the geologist would know that this limestone might belong to one of several stages in the series, and it would be necessary to ascertain what particular limestone was here exposed. But one such rock is very much like another in general appearance, and the stratigraphical evidence might be so obscure that he could not be sure whether the area in which the limestone occurred had been faulted up or down. Fossils, however, are usually plentiful in calcareous strata, and in such a case their evidence would at once decide the matter. Thus, if the country was England, and among the fossils found, *Asaphus tyrannus*, *Trinucleus fimbriatus*, and *Lingula attenuata* occurred, there would be little hesitation in referring the limestone to the Llandeilo group; if, however, *Asaphus Powisii* and *Trinucleus concentricus* occurred, associated with other fossils characteristic of the Bala limestone (see list), the point would be decided in favour of that formation; while, lastly, *Phacops caudata*, *Orthis rustica*, *Atrypa reticularis*, etc., would prove it to be a limestone of

the Wenlock group. Even the three different limestones of the Silurian series may be distinguished by the different fossil assemblages they contain, for though many species are common to all, some are far more abundant in one than in either of the others (see p. 281).

It is necessary, however, to observe a certain amount of caution in the use of palæontological evidence. The mode of procedure indicated in the above examples necessarily presupposes that the stratigraphical succession has first been established in some other locality where the relative position of the beds is clearly seen, so that there can be no doubt about the comparative age of the faunas they contain. In other words, the successional order of the faunas must first be clearly ascertained before the observer can apply his knowledge to the elucidation of unexplored districts or faulted and complicated areas. Another caution must also be given, viz.: that the minuteness and accuracy with which two formations can be compared, depends on the amount of similarity between the fossil contents, whether, in fact, they were accumulated within the limits of the same natural province. The laws which regulate the distribution of life at the present time, governed it also during past periods, and though the provinces may have been larger in early periods, such regions certainly existed, and we have no record of a time when the whole earth was covered by the same fauna and flora. Consequently the successive assemblages in one region will not be the same as those in another, and we cannot expect that the rocks of distant countries will contain the same fossil animals and plants as are found in the rocks of the British Islands.

Even in comparing the rocks of adjacent districts it will sometimes be found that there is only a general correspondence between their fossils, for if they belonged to different provinces neither the genera nor the species will be exactly the same; in such a case the knowledge of the fossils of one series will not help us much in deciding the relative age of any portion of the other series, neither will it be safe to assume that any part of the one was exactly contemporaneous with any part of the other.

Again, in comparing the rocks of distant countries it sometimes happens that the correspondence between two formations is very close, the same assemblage of genera perhaps existing in both, though the representative species are different; it is clear that they occupy the same position in the geological series of the two countries, and we might suppose that they were absolutely contemporaneous; this, however, would be a rash conclusion, for 'it is yet doubtful,' says Mr. Jukes, 'whether these specific differences, existing together with generic identities, be due to a want of exact synchronism in the age of the beds or to the geographical distribution and limitation of the life of the period, whether in fact they are the result of time or space.'

In correlating such formations we can only say that the order of succession is the same in both regions, and as regards the corresponding or equivalent divisions, we should be careful to speak of them as *homotaxial* and not *contemporaneous*. For instance, rocks in Bohemia and Scandinavia, containing the same genera of trilobites as are found in our Lingula flags, have been correlated with them and with one another, as if they were abso-

lutely coeval. Strictly speaking, however, they can only be regarded as *co-ordinate* or *homotaxial.*

From the preceding considerations we learn that a knowledge of the general succession of generic forms will enable us to fix the relative age of any group of fossils that we find in any part of the world. Further, that in a limited district, if we are acquainted with the specific forms occurring in any bed or group of beds, and find the same assemblage in other beds, we may regard the two groups as being of the same age and belonging to the same formation. These results may be briefly stated as follows:

1. *Assemblages of identical genera may be regarded as homotaxial.*
2. *Assemblages of identical species may be regarded as contemporaneous.*

Palæontological Zones.—This last proposition admits of very minute application in the case of certain Neozoic formations, where the conditions controlling the evolution and distribution of life appear to have changed more rapidly than the physical conditions affecting the lithological constitution of the deposits; so quickly is one group of species succeeded by another that palæontological divisions may be made in a thick formation of clay or limestone, in which there is little variation of lithological character. These divisions are called *zones,* and they can sometimes be traced over a large district; but of course they will not extend beyond the limits of the marine area or province in which the particular formation was deposited.

Prof. Judd has some excellent observations on the value of such zones* from which we quote the following: 'By the adoption of zones of life, palæontologists endeavour to indicate the well ascertained fact that in consequence of the mode of distribution of the forms of life in a formation, certain horizons in it can be recognised—either by the restriction of the range of certain groups of species, or by the peculiar assemblage of these, or by their greater or less relative abundance between certain vertical limits. These species are not uniformly the same over a great area: many of the highly abundant and most characteristic forms of one locality, indeed, becoming rare or entirely disappearing, or being replaced by others at a different point, while the *general assemblage* of forms, nevertheless, remains the same. Though the *zones* have a real existence, their *limits* are not usually sharply defined; and even when such is the case the cause of the break may usually be traced to the absence of beds representing the intermediate zones. The tendency of continued study over large areas is, by the detection of intermediate zones of life at particular points, to make our knowledge of the whole series more complete, and thus to render the gradation between its subdivisions more imperceptible.'

It is the custom to indicate a zone by giving it the name of some prevalent and characteristic species, such as 'zone of *Ammonites communis*,' 'zone of *Holaster subglobosus*;' this custom, however, has led to a misunderstanding in regard to the real nature of zones. Some have supposed that any beds containing the fossil thus singled out must belong to that particular zone which bears its name; this, however, does not follow; the species selected may or may not be absolutely confined to the zone, in which it is especially abundant, and where it is associated with the peculiar group of fossils of which it is chosen as the index.

* 'Geology of Rutland,' Mem. Geol. Surv., p. 48.

Zones, when their nature is thus properly understood, afford the greatest assistance to the geologist endeavouring to read the history of the rocks he has studied and mapped. As a method of classification, they are invaluable; thus before the zonal system was applied to the Lias, it was only found possible to divide that formation into three very unequal stages, now, however, the Lower Lias alone is subdivided into no less than ten zones. The Chalk affords another instance in which the old classification, founded on minor lithological differences, was unsatisfactory, and for which a zonal classification is now being adopted.

Some of the sections previously described will illustrate the existence of these zones in the English Chalk, for the species mentioned as occurring in the several pits indicated on the maps (figs. 5, 7, and 8) are such as have been actually found in a similar series of sections, and it will be noticed that each horizon yields a different group of species.

The lowermost zone exposed at the top of the sand-pit *a* has been called that of *Plocoscyphia meandrina*, from the sponge of that name which is often found in it. Quarry *d* exposes the 'Totternhoe Stone,' a subsidiary horizon of the zone of *Holaster subglobosus*, and wherever this sandy stone occurs, its outcrop can be readily traced by the strong springs thrown out at its base. The higher part of this zone is not exposed by any section in the area described, but it is often quarried and always contains the characteristic Echinoderm. Quarry *l* shows the hard beds which occur in one part of England between the last-mentioned zone and that of *Rhynchonella Cuvieri;* it has already been stated (p. 229) that *Belemnites plenus* is characteristic of this horizon, though it is not always a common fossil. *Holaster subglobosus* has never yet been found above these beds, and very few of its associates pass into the middle beds of the Chalk which are divisible into two or three zones, containing certain Echinoderms which are not found in any other part of

the Chalk. The hard rock mentioned as seen in quarry *g* is taken as another divisional line which appears to coincide with a faunal change; certain species of *Micraster* become very abundant above this rock, and are associated with *Cidaris sceptrifera* and *Ananchytes ovatus.* In still higher beds we find other varieties of *Micraster* with *Galerites conicus* and other fossils, some of which are mentioned on p. 229, from the quarry *k*.

If our survey were carried still further, we should find that beyond these there were beds characterised by another assemblage of forms among which *Marsupites* and *Belemnitella mucronata* would be conspicuous. A table of the zones already established is given on p. 288, and these have been traced over most of the Chalk districts in England.

After a district has been surveyed in the manner described in the first part of this book, it may happen that the examination of the fossils collected will reveal the existence of palæontological zones in one or more of the formations, or they may be discovered during the progress of the work. A brief revision of the area will often render it possible to draw lines on the map which shall roughly indicate the limits of these divisions. Slight lithological differences are often found to co-exist with the faunal differences, and rocky, marly, or sandy layers sometimes occur between two well-marked zones; these may be only local developments, but all such facts and indications will assist the geologist in laying down such zonal boundary lines. Wherever it is practicable we would recommend the mapping of these minor divisions, if it were only to ensure the thorough investigation of every formation in the series.

Practical Use of Palæontology.—The application of fossil evidence has often a very practical bearing, and

of this many instances may be found in the history of coal-mining; it has frequently happened that much labour and money have been fruitlessly wasted in the search for coal, which would have been prevented by the slightest acquaintance with the laws of palæontology, the beds through which shafts have been sunk yielding fossils, not of the species mentioned on p. 283, but such as are characteristic of Silurian shales or Kimeridge clay.

The late Mr. J. B. Jukes says: 'I have known, even in the rich coal district of South Staffordshire, shafts continued down below the Coal-measures, deep into the Silurian shales, with crowds of fossils brought up in every bucket, and the sinker still expecting to find coal in beds below those Silurian fossils. I have known deep and expensive shafts sunk in beds too far above the coal-measures for their ever being reached, and similar expensive shafts sunk in black shales and slates in the lower rocks far below the coal-measures, where a pit might be sunk to the centre of the earth without ever meeting with coal. Nor are these fruitless enterprises a thing of the past. They are still going on in spite of the silent warnings of the fossils in the rocks around, and in spite of the loudly-expressed warnings of the geologists, who understand them, but who are supposed still to be vain theorists, and not to know so much as the "*practical man.*" Within my own experience large sums of money have been absolutely thrown away, which would have been saved by the slightest acquaintance with the laws of palæontology.'*

In all deep sinkings the fossils brought up in the cores are most useful in fixing the exact horizon which has been reached, and without their aid it is sometimes impossible to determine the age of the rock that is pierced. That of the rocks which underlie the Cretaceous Series below London has only lately

* 'Students' Manual of Geology,' third edition, p. 512.

been decided by means of such evidence. The boring made at Kentish Town about twenty years ago reached these beds, but no fossils were found in them; the question of their age therefore remained undecided until 1878, when the boring made by Messrs. Meux and Co. pierced similar beds, which contained fossils that proved to be Devonian species.* Other subsequent borings at Turnford and Ware, twenty and twenty-five miles N. of London, have determined the presence at the former place of the Devonian, and at the latter of the Wenlock shales. These discoveries may lead to important practical results, from the bearing they have on the probable occurrence of Coal-Measures under the London Basin.

From a consideration of the points discussed in the present chapter, we arrive at the conclusion that Palæontology, though based upon the facts of stratigraphical geology, is often a far surer guide than geognosy can be. At the same time, it is necessary to be cautious, for too exclusive a reliance upon palæontological results, without due consideration of the stratigraphical evidence, may lead to error; we have pointed out the conditions under which palæontological rules may be relied upon with tolerable certainty, and likewise the cases in which they do not admit of precise and accurate application. It is clear, therefore, that the geologist should pursue both branches of his science with equal assiduity, and in all questions which concern rocks containing organic remains, the one line of inquiry should be used to check the other. The observer who is thus led by convergent paths to the same result is not likely to be far wrong in his conclusions.

* See Quart. Journ. Geol. Soc. vol. xxxiv. p. 902.

CHAPTER V.

CHARACTERISTIC FOSSILS.

In the last chapter we explained what is meant by a characteristic genus or species, and showed how far strata may safely be identified by means of their fossil contents. A fossil may be characteristic of a zone or formation without being absolutely confined to it, and without being of very frequent occurrence. Characteristic fossils fall naturally under two heads; they may be either—(1) genera or species exclusively confined to a particular formation (these may be either common or rare); (2) genera or species specially abundant on one particular horizon, or during a certain period (these may or may not range into other formations).

The following tables have been drawn up with the view of furnishing the student with the means of identifying the beds under his investigation. A comparatively small amount of palæontological knowledge will enable him to use the first set of tables, which indicate the genera characteristic of the beds composing the successive geological systems, the genera in each table being grouped zoologically under their respective classes. These tables are capable of more or less universal application, and consequently they may be used to ascertain

the relative age of any fossiliferous formation, even if little or nothing is known of the geology of the country in which it occurs.

The genera which are specially characteristic (*i. e.*, which are confined to one particular period, and are not known to have existed in older or later times) are printed in italics; those in ordinary type have a wider range in time, though most of them attained their maximum of development during the period under which they are placed. 'Persistent types' will recur for several periods. Those genera to which an asterisk is affixed are not found in England, but characterise rocks belonging to the same system in other parts of the world.

The second set of tables have been added to complete the diagnosis for the British Isles and the western portion of Europe; they contain some of the species which are specially characteristic of the sub-divisions composing the larger geological systems. The names are added of the species characterising the principal zones, which have been recognised in some of the Mesozoic formations.

There is still much difference of opinion with regard to the grouping of the older Palæozoic rocks; the classification here adopted is that by Mr. H. B. Woodward in his 'Geology of England and Wales'; the only exception being in the case of the Lower Llandovery Beds, which are dissociated from the Upper beds of the same name, and placed in the Lower Silurian system.

CHARACTERISTIC GENERA.

CAMBRIAN SYSTEM.

LOWER AND MIDDLE CAMBRIAN.

PLANTÆ. *Cruziana*, Fucoides, *Palæochorda*.
PROTOZOA. **Archæocyathus*, *Astylospongia, *Protospongia*.
HYDROZOA. Dictyonema.
ECHINODERMATA. Dendrocrinus, Palasterina, *Protocystites*.
ANNELIDA. Arenicolites, *Histioderma*, Scolites, *Trachyderma*.
CRUSTACEA. Agnostus, Angelina, *Anopolenus*, Arionellus, *Carausia*, Conocoryphe (Conocephalus), Dikellocephalus, *Erinnys*, Ellipsocephalus, Entomis, *Hymenocaris*, Leperditia, *Lingulocaris*, *Microdiscus*, *Neseuretus*, *Niobe*, *Olenus*, *Oldhamia*, *Paradoxides*, *Plutonia*, Primitia, **Sao*, Sphærophthalmus.
BRACHIOPODA. Discina, Lingulella, Obolella.
LAMELLIBRANCHIATA. Ctenodonta, Davidia, Modiolopsis, *Glyptarca*, Palæarca.
GASTEROPODA AND PTEROPODA. Theca, *Cyrtotheca*, *Ophileta*.
CEPHALOPODA. Cyrtoceras, Orthoceras.

UPPER CAMBRIAN

(Including the Arenig Group).

PROTOZOA. *Astylospongia, **Acanthospongia*, **Eospongia*, **Palæomanon*, **Palæospongia*, **Sphærospongia*, Stromatopora.
HYDROZOA. *Callograptus*, *Cladograptus*, *Climacograptus*, *Dendrograptus*, *Dicellograptus*, *Dichograptus*, Didymograptus, *Diplograptus*, Dictyonema, Graptolithus, Phyllograptus, Ptilograptus, *Rastrites*, *Tetragraptus*.
ACTINOZOA. Favosites, Heliolites, Halysites, Monticulipora (*chiefly in the Bala group, with other genera ranging into the Silurian System*).
ECHINODERMATA. *Agelacrinus*, *Caryocystites*, *Echinosphærites* Glyptocrinus, *Hemicosmites*, Palæaster, Stenaster.

ANNELIDA. *Conchicolites, Crossopodia, *Lumbricaria*, *Myrianites*, *Nemertites*, *Nereites*, Tentaculites.

CRUSTACEA. Acidaspis, *Æglina*, Agnostus, *Amphion, Ampyx, *Asaphus*, Beyrichia, Calymene, *Caryocaris*, Cheirurus, *Cybele*, Encrinurus, Harpes, Homalonotus, Illænus, Lichas, Ogygia, Phacops, *Remopleurides*, *Staurocephalus*, *Trinucleus*.

BRACHIOPODA. Atrypa, Discina, Leptæna, Lingula, Obolus, Obolella, Orthis, Rhynchonella, Siphonotreta, Strophomena, Trematis.

LAMELLIBRANCHIATA. Ambonychia, Ctenodonta, Cyrtodonta, Modiolopsis, Orthonota, Palæarca, Pterinæa.

GASTEROPODA, PTEROPODA, AND HETEROPODA. Bellerophon, Conularia, Euomphalus, Holopea, *Maclurea*, Murchisonia, *Ophileta*, Pleurotomaria, Pterotheca, Raphistoma, Theca.

CEPHALOPODA. Cyrtoceras, Lituites, Orthoceras, Pyloceras.

SILURIAN SYSTEM.

PROTOZOA. **Amphispongia*, **Favospongia*, *Ischadites*, *Receptaculites*, Stromatopora, Caunopora, *Cænostroma.

HYDROZOA. Cyrtograpsus, Graptolithus, *Retiolites*.

ACTINOZOA. Acervularia, Alveolites, Arachnophyllum, *Aulacophyllum*, Chætetes, *Cœnites*, Cyathophyllum, Cystiphyllum, Favosites, *Goniophyllum*. *Halysites*, Heliolites, *Labechia*, *Omphyma*, *Palæocyclus*, *Ptychophyllum*, Strombodes, Syringopora, *Thecia*.

ECHINODERMATA. *Apiocystites*, *Crotalocrinus*, Cyathocrinus, *Dimerocrinus*, *Echinoencrinus*, *Enallocrinus*, *Eucalyptocrinus*, *Lepidaster*, *Marsupiocrinus*, Palæaster, *Palasterina*, *Palæocoma*, Periechocrinus, *Prunocystites*, *Pseudocrinus*, *Protaster*, *Palæodiscus*.

ANNELIDA. *Cornulites*, Serpulites, Spirorbis, Tentaculites.

CRUSTACEA. Acidaspis, Ampyx, Beyrichia, Calymene, Ceratiocaris, Cheirurus, *Cyphaspis*, Encrinurus, Homalonotus, Illænus, Leperditia, Lichas, Phacops, *Proetus*.

Eurypterus, *Hemiaspis*, Pterygotus, *Slimonia*.

POLYZOA. Ceriopora, Discopora, Fenestella, Glauconome, Ptilodictya.

BRACHIOPODA. Athyris, Atrypa, Discina, Leptæna, Lingula, Orthis, Meristella, Pentamerus, Retzia, Rhynchonella, Siphonotreta, Spirifera, Strophonema.

LAMELLIBRANCHIATA. Cardiola, *Clidophorus*, Ctenodonta, *Grammysia*, Modiolopsis, Orthonota, Pterinea.

GASTEROPODA, PTEROPODA, AND HETEROPODA. Acroculia (Capulus), Bellerophon, Cyclonema, Conularia, Euomphalus, Holopella, Loxonema, Macrocheilus, Murchisonia, Platychisma.

CEPHALOPODA. *Actinoceras*, Ascoceras, Cyrtoceras, Gomphoceras, Lituites, Orthoceras, Phragmoceras, *Trochoceras*.

PISCES. Auchenaspis, Cephalaspis, Onchus (?), Pteraspis, Plectrodus, Sphagodus.

(?) DEVONIAN SYSTEM.

A. DEVONIAN BEDS.

PLANTÆ. Cyclopteris, Knorria, etc.

(N.B. The American Devonians contain many others common to the Carboniferous System.)

PROTOZOA. *Sparsispongia, Stromatopora, Caunopora, *Cænostroma.

ACTINOZOA. Acervularia, Arachnophyllum, Alveolites, Aulopora, Amplexus, Battersbyia, Cyathophyllum, Favosites, Heliolites, Hallia, *Pleurodictyum*, *Rhizophyllum* (*Calceola*), *Smithia*.

ECHINODERMATA. *Cupressocrinus*, Cyathocrinus, *Hexacrinus, *Haplocrinus*, *Melocrinus*.

CRUSTACEA. Bronteus, Cheirurus, Cypridina, *Dictyocaris*, Estheria, Harpes, Homalonotus, Phacops, **Proricaris*.

BRACHIOPODA. Atrypa, Chonetes, *Davidsonia*, *Merista*, Meristella, Orthis, Spirifera, *Stringocephalus*, *Streptorhynchus*, *Uncites*.

LAMELLIBRANCHIATA. Aviculo-pecten, Cucullella, Curtonotus, Megalodon, Orthonota, Pterinea.

GASTEROPODA, PTEROPODA, AND HETEROPODA. Acroculia, Bellerophon, Conularia, Euomphalus, Macrocheilus, Murchisonia, Pleurotomaria, Trochus.

CEPHALOPODA. **Bactrites*, *Clymenia*, Cyrtoceras, Goniatites, *Gyroceras*, Nautilus, Orthoceras.

B. OLD RED SANDSTONE.

PLANTÆ. Asterophyllites, Calamites, Cyclopteris, Cordaites, Cyclostigma (Lepidodendron), Neuropteris, *Psilophyton*, Sagenaria, Sphenopteris.

CRUSTACEA. Eurypterus, Pterygotus, Stylonurus.

LAMELLIBRANCHIATA. Anodonta.

PISCES. Acanthodes, Asterolepis, Cephalaspis, **Climatius*, Coccosteus, Cheiracanthus, Ctenacanthus, Dendrodus, *Diplacanthus*, *Dipterus*, *Diplopterus*, *Eucephalaspis*, *Glyptolepis*, *Glyptolæmus*, *Glyptopomus*, Holoptychius, *Osteolepis*, Pamphractus, *Phaneropleuron*, Pteraspis, Pterichthys, Scaphaspis.

CARBONIFEROUS SYSTEM.

PLANTÆ. Alethopteris, Annularia, *Antholites*, Asterophyllites, Calamites, Calamodendron, Cardiocarpon, *Caulopteris*, Cyclocladia, Cyclopteris, *Dadoxylon*, *Hymenophyllites*, *Favularia*, Lepidodendron, Neuropteris, Nœggerathia, Odontopteris, Pinites, Palæoxylon, Pecopteris, Pinnularia, *Pothocites*, Sagenaria, Sigillaria, Sphenopteris, Stigmaria, Trigonocarpum, Ulodendron.

PROTOZOA. Amphistigina, *Fusulina*, ° Loftusia, Saccamina, Trochammina.

ACTINOZOA. Alveolites, Amplexus, *Aulophyllum*, Chætetes, Cyathophyllum, *Clisiophyllum*, *Lithostrotion*, *Lonsdalia*, *Michelinia*, Syringopora, *Zaphrentis*.

ECHINODERMATA. Actinocrinus, Archæocidaris, *Codonaster*, Cyathocrinus, Palæchinus, *Platycrinus*, Poteriocrinus, *Pentremites*, Rhodocrinus, Taxocrinus, *Woodocrinus*.

CRUSTACEA. *Anthrapalæmon*, Belinurus, *Brachymetopus*, Dithyrocaris, *Griffithides*, *Phillipsia*, *Prestwichia*, Palæocrangon, Pygocephalus.—Bairdia, Candona, Cythere, Cypris, Cypridina, Estheria, Leperditia.

ANNELIDA. Microconchus (Spirorbis), *Spiroglyphus*.

POLYZOA. *Archemedipora, Fenestella, Ptilopora, Retepora, Polypora.

BRACHIOPODA. Athyris, Chonetes, Cyrtia, Discina, Lingula, Orthis, Producta, Rhynchonella, Spirifera, Terebratula.

LAMELLIBRANCHIATA. *Anthracosia*, Aviculopecten, Axinus, Conocardium, Cardiomorpha, Ctenodonta, Edmondia, Leda, Pleurophorus, Posidonomya, *Sedgwickia*.

GASTEROPODA AND PTEROPODA. Bellerophon, Conularia, Euomphalus, Loxonema, Macrocheilus, Naticopsis, Platychisma, Pleurotomaria, Porcellia.

CEPHALOPODA. Clymenia, *Discites*, Goniatites, Nautilus, Orthoceras.

PISCES. Amblypterus, Cladodus, *Cochliodus*, Cœlacanthus, Ctenodus, Ctenacanthus, Gyracanthus, Holoptychius, Megalicthys, *Orodus*, *Orthacanthus*, *Pleuracanthus*, *Psammodus*, *Petalodus*, *Rhizodus*.

AMPHIBIA. *Archegosaurus*, *Anthracosaurus*, *Baphetes*, **Dendrerpeton*, *Erpetocephalus*, *Batrachiderpeton*, *Ichthyerpeton*, *Lepterpeton*, *Ophiderpeton*.

PERMIAN SYSTEM.

PLANTÆ. Alethopteris, Annularia, Asterophyllites, Calamites, Callipteris, Equisetites, Huttonia, Lepidodendron, Nœggerathia, Odontopteris, Pecopteris, Psaronius, Sphænopteris, Tæniopteris, *Ullmannia*, *Walchia*.

ACTINOZOA. *Polycœlia*, Chætetes.

ECHINODERMATA. Archæocidaris, Cyathocrinus (few others known).

CRUSTACEA. Dithyrocaris, Prosoponiscus (few and rare).

POLYZOA. Acanthocladia, Fenestella, *Synocladia*, Phyllopora, Thamniscus.

BRACHIOPODA. Athyris, Camarophoria, Discina, Lingula, Producta, Spirifera, Strophalosia, Terebratula.

LAMELLIBRANCHIATA. Avicula (Monotis), Allorisma, Astarte, Axinus (Schizodus), *Bakewellia*, Cardiomorpha, Myalina, Mytilus, Pleurophorus, Solemya.

GASTEROPODA, ETC. Conularia, Loxonema, Macrocheilus, Naticopsis, Pleurotomaria.

CEPHALOPODA. Nautilus.

PISCES. Acrolepis, Acanthodes, Cælacanthus, *Gyropristis.* Palæoniscus, Platysomus, Pygopterus.

REPTILIA. *Proterosaurus*, *Rhopalodon*, **Zygosaurus.*

TRIASSIC SYSTEM

(Including the Rhætic, Hallstadt, and St. Cassian beds).

PLANTÆ. **Æthophyllum*, *Anomopteris, *Calamites, setites, *Pterophyllum, *Sagenopteris, *Voltzia, *Zamites.

PROTOZOA. Cristellaria, Nubecularia, Bulimina, Dentalina, Nodosaria, Polymorphina, Vaginulina, *Amorphospongia, *Cupulispongia, *Leiospongia, *Stellispongia.

ACTINOZOA. *Acrosmilia, *Eunomia, *Montlivaltia, *Synastrea.

ECHINODERMATA. *Aspidura, *Encrinus, *Cidaris, *Ophiura.

CRUSTACEA (rare). Estheria, **Galatea*, **Litogaster*, *Tropifer.

BRACHIOPODA. *Camarophoria, *Cyrtia, *Discina, **Koninckia*, *Spiriferina, *Terebratula, *Thecidium.

LAMELLIBRANCHIATA. Avicula, Anatina, *Anaplophora*, Gervillia, **Halobia*, *Isoarca, Lima, Monotis, **Myophoria*, *Myoconcha, *Opis, Pecten *Pleurophorus, Plicatula, Pullastra, *Trigonia.

GASTEROPODA. *Chemnitzia, *Loxonema, *Murchisonia, **Naticella*, *Nerinæa, **Platystoma*, *Porcellia, **Scoliostoma.*

CEPHALOPODA. *Ammonites, *Arcestes, *Belemnites, **Ceratites*, *Cyrtoceras, *Goniatites, *Nautilus, *Orthoceras, **Trachyceras.*

PISCES. Amblypterus, Acrodus, Ceratodus, Gyrolepis, Hybodus, Lophodus, Pemphis, Palæoniscus, Saurichthys.

REPTILIA. **Belodon*, **Dicynodon*, *Hyperodapedon*, Labyrinthodon, **Notosaurus*, **Oudenodon*, *Palæosaurus*, *Placodus, *Rhynchosaurus*, **Simosaurus*, *Stagonolepis*, *Telerpeton*, *Thecodontosaurus*, *Trematosaurus.*

MAMMALIA. **Dromatherium*, *Microlestes.*

JURASSIC SYSTEM.

PLANTÆ. Araucarites, Aroides, Bucklandia, Bennettites, Brachyphyllum, Coniopteris, *Crossozamia, Ctenis, Cycadeoidea, Cycadeostrobus, Dammarites, *Dictyopteris, Equisetites, *Glossopteris*, Kaidacarpum, Mantellia, Naiadites, Nillsonia, *Otopteris*, Otozamites, Palæozamia, Pecopteris, Phlebopteris, Pterophyllum, Sphenopteris, Thuytes, *Tæniopteris*, Williamsonia, Zamites.

PROTOZOA. Cristellaria, Dentalina, Frondicularia, Glandulina, Involutina, Lagena, Lingulina, Marginulina, Nodosaria, Planularia, Polymorphina, Spirilina, Trochammina, Vaginulina.—Actinospongia, Chenendopora, Cribrospongia, Porospongia, Scyphia.

ACTINOZOA. Anabacia, Astrocœnia, Calamophyllia, Cladophyllia, *Comoseris*, Cyathocœnia, Eunomia, *Isastræa*, Lepidophyllia, Montlivaltia, Protoseris, Septastrea, *Stylina*, *Thamnastrea*, *Thecosmilia*, Trochocyathus.

ECHINODERMATA. *Acrosalenia*, *Apiocrinus*, Astropecten, Cidaris, *Clypeus*, Collyrites, *Echinobrissus*, *Extracrinus*, *Glypticus*, *Hemipedina*, *Hemicidaris*, Holectypus, Hyboclypus, *Magnosia*, Ophioderma, Ophiolepis, Pedina, Pentacrinus, *Polycyphus*, Pseudodiadema, *Pygurus*, Pygaster, *Stomechinus*, Uraster.

CRUSTACEA. *Archæoniscus*, Cypris, Cypridea, *Eryon*, Eryma, Glyphæa, *Megacheirus*, *Palinurina, Pollicipes, Pseudoglyphæa, *Scaphius*.

POLYZOA. Berenicia, Bidiastopora, *Defrancia*, Diastopora, Entalophora, Eschara, Idmonea, Heteropora, Neuropora, Spiropora, Tubulipora.

BRACHIOPODA. Crania, Discina, Lingula, Rhynchonella, Spiriferina, Terebratula, Thecidium, Waldheimia.

LAMELLIBRANCHIATA. Avicula, Arca, Astarte, Cardinia, Cardium, *Ceromya*, Cyrena, Diceras, Exogyra, Goniomya, *Gryphæa*, Gervillia, *Gresslya*, *Hippopodium*, Isocardia, Lima, Lucina, Modiola, Myacites, Opis, Ostrea, Pecten, *Pachyrisma*, Pholadomya, *Pteroperna*, Trigonia, *Trichites*, Tancredia.

GASTEROPODA. Alaria, Bulla, Cerithium, Chemnitzia, *Cylindrites*, Natica, Nerita, *Neritoma*, Nerinæa, Patella, Pleurotomaria, *Pileolus*, *Purpuroidea*, *Rimula*, *Trochotoma*.

CEPHALOPODA. Ammonites, Belemnites, *Beloteuthis*, *Coccoteuthis*, *Geothuthis*, *Leptoteuthis*, Nautilus.

PISCES. Acrodus, *Æchmodus*, *Aspidorhyncus*, Asteracanthus, Belonostomus, Cardiodon, Chondrosteus, *Dapedius*, Eugnathus, Ganodus, Gyrodus, *Heterolepidotus*, Hybodus, Ischyodus, Lepidotus, Leptolepis, Microdon, Myriacanthus, Pachycormus, *Pholidophorus*, Pycnodus, Sphærodus, Strophodus.

REPTILIA. Cetiosaurus, *Compsognathus*, Chelone, *Dakosaurus*, *Dimorphodon*, *Eurosternum, Goniopholis, Ichthyosaurus, *Macellodon*, Megalosaurus, *Nothetes, Plesiosaurus, Pleurosternon, *Pliosaurus*, Ramphorhynchus, Steneosaurus, *Teleosaurus*.

AVES. **Archæopteryx*.

MAMMALIA. *Amphitherium*, *Amphilestes*, *Galestes*, *Phascolotherium*, *Plagiaulax*, *Spalacotherium*, *Stereognathus*, *Triconodon*.

CRETACEOUS SYSTEM.

PLANTÆ. *Alnus, *Araucaria, Benettites, *Cinnamonum, Clathraria, *Cornus, Credneria, *Cupressus, *Cycadopteris, *Endogenites*, *Ficus, *Juglans, *Liriodendron, Lonchopteris, *Pandanus, Pinites, *Platanus, *Populus, *Quercus, *Salix, *Sassafras, *Sequoites, *Thuites, *Taxodium.

(N.B. Many of these only occur in the uppermost members of the system.)

PROTOZOA. Bulimina, Cristellaria, Cuneolina, Dentalina, Flabellina, Frondicularia, Globigerina, Lagena, Lituola, Marginulina, Nodosaria, Orbitolina, Rotalia, Rotalina, Rosalina, *Parkeria*, Textularia, Vaginulina.

Brachiolites, *Cephalites*, Chenendopora, *Choanites*, Cliona, *Coscinopora*, Guettardia, Manon, *Pharetrospongia*, *Plocoscyphia*, *Polypothecia*, Scyphia, Siphonia, Spongia, *Stauronema*, *Ventriculites*, Verticillites.

ACTINOZOA. *Astrocœnia*, Caryophyllia, Cyathina, *Cyclocyathus*,

Holocystis, *Micrabacia*, *Parasmilia*, Placosmilea, *Stephanophyllia*, *Trochosmilia*, Trochocyathus.

ECHINODERMATA. *Ananchytes*, Astrogonium, *Bourgeticrinus*, Cidaris, *Cardiaster*, Catopygus, *Cyphosoma*, *Discoidea*, Diadema, Echinoconus, Echinobrissus, Echinocyphus, Echinospatagus, Epiaster, *Galerites*, Goniodiscus, Goniaster, *Hemiaster*, *Hemipneustes*, *Holaster*, *Marsupites*, *Micraster*, Oreaster, Pentacrinus, Pseudodiadema, Peltastes, Pyrina, Salenia, Stellaster, Trematopygus.

CRUSTACEA. Cypridea, *Enoploclytia*, *Etyus*, Hoploparia, *Meyeria*, Glyphæa, *Necrocarcinus*, Palæocorystes, Pollicipes.

ANNELIDA. Serpula, Vermicularia.

POLYZOA. Ceriopora, Eschara, Escharina, Entalophora, Flustra, Heteropora, Hornera, Homœosolen, Lunulites, Membranipora, Radiopora, Reticulopora, Tubulipora, Vincularia.

BRACHIOPODA. Crania, *Kingena*, *Magas*, Rhynchonella, Terebratula, Terebratulina, Terebratella, *Terebrirostra*, Thecidium.

LAMELLIBRANCHIATA. Arca, Astarte, Avicula, *Caprina*, Cardium, Corbis (Sphæra), Cucullæa, Cyrena, Cyprina, *Exogyra*, *Hippurites*, Inoceramus, Lima, Gervillia, Ostrea, Nucula, Panopea, Perna, Pecten, Plicatula, *Radiolites*, *Requienia*, Spondylus, Thetis, Trigonia, Unicardium.

GASTEROPODA. Actæon, Aporrhais, *Avellana* (Cinulia), *Bellerophina*, Cerithium, Dentalium, Litorina, Natica, Nerinæa, Neritina, Paludina, Pleurotomaria, Scalaria, Solarium, Turritella, Trochus, *Vicarya*.

CEPHALOPODA. Ammonites, Ancyloceras, *Baculites*, Belemnites, *Belemnitella*, *Conoteuthis*, *Crioceras*, *Hamites*, *Ptychoceras*, *Scaphites*, *Toxoceras*, *Turrilites*.

PISCES. Beryx, Caturus, Corax, Edaphodon, Ischyodus, Gyrodus, Lamna, Lepidotus, *Macropoma*, Notidanus, Odontaspis, Otodus, Oxyrhina, **Protosphyræna*, Pycnodus, *Ptychodus*, *Saurocephalus*.

REPTILIA. Chelone, Dolichosaurus, Goniopholis, *Hylæosaurus*, *Iguanodon*, Ichthyosaurus, *Mosasaurus*, Plesiosaurus, *Polyp-*

tychodon, Pterodactylus, Protemys, *Streptospondylus*, Tretosternon.

AVES. *Enaliornis* (British), *Hesperornis*, *Ichthyornis*, *Laornis*, *Lestornis*, *Palæotringa*, *Scolopax*, *Telmatornis* (American).

EOCENE SYSTEM.

PLANTÆ (European only). Acacia, Aralia, Cassia, Cæsalpina, Casuarina, Chara, Cupressites, Dryandra, Flabellaria, Ficus, Hightia, Laurus, Leguminosites, *Nipadites*, Pinites, Palmacites, Petrophylloides, Podocarpus, Pterocarpus, *Wetherellia*, Zizyphus.

PROTOZOA. Acicularia, Alveolina, *Calcarina, Cornuspira, Dentalina, Discorbina, Lagena, *Miliola, Nummulites, Operculina, Orbitolites, Ovulina, Peneroplis, Planorbulina, *Quinqueloculina, Rotalina, *Spirulina, *Triloculina, Valvulina.

ACTINOZOA. Axopora, Balanophyllia, Dasmia, Dendrophyllia, *Litharea*, Madrepora, Oculina, Paracyathus, *Solenastrea*, Turbinolia.

ECHINODERMATA. Astropecten, Eupatangus, Goniaster, Ophiura, Pentacrinus.

CRUSTACEA. *Archæocarabus*, *Dromilites*, Hoploparia, Xanthopsis.

ANNELIDA. Ditrupa, Serpula, Vermicularia.

POLYZOA. Eschara, Flustra.

BRACHIOPODA. Lingula, Terebratula, Terebratulina.

LAMELLIBRANCHIATA. Arca, Cardita, Chama, Corbula, Crassatella, Cryptodon, Cyrena, Cyprina, Leda, *Lithocardium*, Ostrea, Nucula, Panopea, Pectunculus, Pholadomya, Pinna, Potamomya, Protocardium, *Teredina*, Venus.

GASTEROPODA. Achatina, Ancillaria, Aporrhais, Bulimus, Cassidaria, Cancellaria, Cerithium, Conus, Conorbis, Cypræa, Dentalium, Fusus, Globulus, Helix, Hydrobia, Limnæa, Lychnus, Mitra, Melania, Melanopsis, Murex, Natica, Neritina, Oliva, Paludina, Phorus, Planorbis, Pleurotoma, Potamides, *Rimella*, Rostellaria, Terebellum,

Trochus, Turritella, Typhis, *_Velates_, Voluta, _Volutilithes_, _Volvaria, with other recent genera._

CEPHALOPODA. Aturia, Beloptera, Belosepia, Nautilus.

PISCES. *Amia, Carcharodon, Cælopoma, Edaphodon, Galeocerdo, Lamna, *Lepidosteus, Lepidotus, Myliobatis, Otodus, Pristis, Tetrapterus.

REPTILIA. Alligator, *_Boavus_, Chelone, Crocodilus, Emys, Gavialis, Palæophis, Trionyx, *_Plastomenus_, *_Limnosaurus_, *_Oreosaurus_, and others.

AVES. *_Alectornis_, _Halcyornis_, *_Gastornis_, _Lithornis_, _Protornis_, *_Unitornis_.

MAMMALIA.

MARSUPIALIA. *Didelphys.

SIRENIA. Halitherium.

CETACEA. *_Zeuglodon_.

UNGULATA. _Anoplotherium_, Anthracotherium, _Chæropotamus_, _Coryphodon_, _Dichobune_, Dichodon, *_Eohippus_, *_Epihippus_, Hyopotamus, *_Hyrachyus_, Lophiodon, Microchærus, Palæotherium, Paloplotherium, Pliolophus, *_Orohippus_.

DINOCERATA. *_Dinoceras_, *_Tinoceras_, *_Uintatherium_.

HYRACOIDEA. _Hyracotherium_.

CARNIVORA. *_Arctocyon_, *Canis, *_Cynodon_, *_Dromocyon_, *Hyænodon, *_Limnofelis_, *_Limno_

*_Orocyon_, *_Sinopa_, *_Uintacyon_.

RODENTIA. *Myoxus, *Sciurus.

CHEIROPTERA. *Vespertilio, *_Nyctilestes_, *_Nyctitherium_.

INSECTIVORA. *_Spalacodon_, *_Talpavus_, *_Centedodon_, *_Entomacodon_, *_Palæacodon_.

QUADRUMANA. *_Hyopsodus_, *_Lemuravus_, *_Limnotherium_.

MIOCENE SYSTEM.

PLANTÆ (European only). Acer, Acacia, Alnus, Andromeda, Banksia, Betula, Cassia, Carpinus, Chamærops, Corylus, Cinnamomum, Daphnogene, Ficus, Grevillia, Glyptostrobus, *Hakea, Lastrea, *Liquidambar, *Liriodendron, *Myrica,

Platanus, Populus, Rhamnus, Sabal, Sequoia, Sparganium, Taxodium.

PROTOZOA. *Amphistegina, *Pullenia, *Textularia, *Calcarina.

ACTINOZOA. *Astrea, *Dendrophyllia.

ECHINODERMATA. *Clypeaster, *Scutella.

POLYZOA. *Lepralia, *Lunulites.

BRACHIÒPODA. *Terebratula.

LAMELLIBRANCHIATA. All the recent genera mentioned as found in the Eocene occur also in the Miocene, together with *Artemis, *Carolia, *Grateloupia, *Jouannetia, *Lucina, *Tapes.

GASTEROPODA. All the recent genera found in the Eocene occur also in the Miocene, together with **Deshaysia*, **Ferussina*, **Halia*, **Proto*, **Vaginella.*

CEPHALOPODA. *Nautilus, **Spirulirostra.*

PISCES. *Carcharodon, *Lamna, *Oxyrhina, etc.

REPTILIA (few known). **Colossochelys*, *Testudo.

MAMMALIA (N.B.—none of these occur in Britain).

MARSUPIALIA. Didelphys.

EDENTATA. *Ancylotherium*, *Macrotherium.*

SIRENIA. Halitherium.

CETACEA. *Champsodelphis*, Delphinus, Squalodon, *Stereodelphis.*

UNGULATA *Acerotherium*, *Anchitherium*, *Anthracotherium*, *Brontotherium*, *Bramatherium*, *Chalicotherium*, *Dorcatherium*, *Dremotherium*, *Diceratherium*, *Elotherium*, *Helladotherium*, *Hipparion*, Hippopotamus, Hyopotamus, Lophiodon, *Miohippus*, *Mesohippus*, *Oreodon*, Sus, *Sivatherium.*

PROBOSCIDIA. *Dinotherium*, Elephas, Mastodon, *Stegodon.*

CARNIVORA. *Amphicyon*, Canis, Ictitherium, *Hyænictis*, Machairodus.

INSECTIVORA. Erinaceus, Talpa, Sorex.

RODENTIA. Castor, Lepus, Mus, etc.

CHEIROPTERA. Vespertilio.

QUADRUMANA. *Dryopithecus*, *Pliopithecus*, *Laopithecus.*

PLIOCENE SYSTEM.

PLANTÆ. The Pliocene flora of Europe closely resembles that now existing in North America, and includes such genera as *Gleditschia, *Liquidambar, *Liriodendron, *Oreodaphne, *Nyssa, *Rhus, *Robinia, and *Taxodium.

PROTOZOA. Orbulina, Operculina, and other recent genera.

ACTINOZOA. Balanophyllia, *Cryptangia*, Flabellum, Sphenotrochus.

ECHINODERMATA. Brissus, Comatula, Echinus, Echinocyamus, *Temnechinus*.

CRUSTACEA (*few known.*)

POLYZOA. Cellepora, *Fascicularia, Theonoa.*

BRACHIOPODA. Argiope, Discina, Lingula, Rhynchonella, Terebratula, Terebratulina.

MOLLUSCA. Of numerous genera, nearly all now existing.

MAMMALIA.

SIRENIA. Halitherium.

CETACEA. *Balænodon*, Xiphius, Choneziphius, Phocena, Plesiocetus.

UNGULATA. Bison, Cervus, Equus, Hippopotamus, Rhinoceros, Sus, **Morotherium*, **Merychyus*, **Merychippus*, **Protohippus*, **Pliohippus*, Tapirus.

PROBOSCIDIA. *Elephas, *Mastodon.

CARNIVORA. Canis, Felis, Machairodus, Ursus.

RODENTIA. **Arctomys*, **Geomys*, **Hystrix*.

TABLES OF CHARACTERISTIC SPECIES FOR THE CHIEF SUBFORMATIONS OF EACH GEOLOGICAL SYSTEM.

CAMBRIAN SYSTEM.

Harlech Beds.

Oldhamia antiqua.	Leperditia prima.
„ radiata.	Agnostus Cambrensis.
Histioderma Hibernicum.	Microdiscus sculptus.
Arenicolites didyma.	Conocoryphe Lyellii.

Menevian Beds.

Agnostus Davidis.	Lingulella ferruginea.
Erinnys venulosa.	Obolella sagittalis.
Conocoryphe Homfrayi.	Theca corrugata.
Paradoxides Davidis.	

Lingula Flags.

Cruziana semiplicata.	Olenus micrurus.
Dictyonema sociale.	Hymenocaris vermicauda.
Agnostus princeps.	Lingulella Davisii.

Tremadoc Slates.

Angelina Sedgwickii.	Neseuretus Ramsayensis.
Niobe Homfrayi.	Modiolopsis Solvensis.
Conocoryphe depressa.	Theca operculata.

Arenig Flags and Skiddaw Slates.

Diplograpsus pristis.	Asaphus Homfrayi.
Dichograpsus Sedgwickii.	Ogygia Selwynnii.
Orthis Carausii.	Trinucleus Gibbsii.

Llandeilo Flags.

Didymograpsus Murchisoni.	Asaphus tyrannus.
Diplograpsus foliaceus.	Ogygia Buchii.
Rastrites peregrinus.	Trinucleus fimbriatus.
Ampyx nudus.	Lingula attenuata.

Bala or Caradoc Beds.

Phacops apiculatus.
Asaphus Powisii.
Illænus Bowmanni.
Trinucleus concentricus.
Echinosphærites Balticus.
Orthis vespertilio.
,, flabellulum.
Leptæna sericea.
Holopea concinna.
Lituites cornu-arietis.

Lower Llandovery Beds.

Petraia subduplicata.
Illænus Thomsoni.
Stricklandinia lens.
Meristella angustifrons.
Murchisonia angulata.
Holopella tennicincta.

SILURIAN SYSTEM.

Upper Llandovery Beds (May Hill Sandstone).

Petraia bina.
Pentamerus oblongus.
Atrypa hemispherica.
Euomphalus prenuntius.

Woolhope Limestone and Shale.

Illænus Barriensis.
Homalonotus delphinocephalus.
Pentamerus linguifer.
Atrypa Grayi.
Meristella didyma.
Retzia Barrandii.
Spirifer exporrectus.

Wenlock Limestone and Shale.

Acervularia luxurians.
Omphyma turbinatum.
Acidaspis Barrandii.
Pterinæa retroflexa.
Spirifer plicatellus.
Euomphalus discors.
Rhynchonella borealis.
Pentamerus galeatus.
Retzia cuneata.
Orthis rustica.
Periechocrinus moniliformis.
Orthoceras annulatum.

Lower Ludlow and Aymestry Limestone.

Pentamerus Knightii.
Rhynchonella Wilsoni.
,, navicula.
Lingula Lewisii.
Pterinæa Sowerbyi.
Cyclonema corallii.
Phragmoceras ventricosum.
Orthoceras ludense.

Upper Ludlow Mudstones.

Phacops Downingiæ.
Homalonotus Knightii.
Rhynchonella nucula.
Discina rugata.
Orthonota amygdalina.
Grammysia cingulata.

Bone Bed and Douriton Sandstone.

Chonetes striatella (lata).	Auchenaspis Salteri.
Lingula cornea.	Cephalaspis Murchisoni.
Platychisma helicoides.	Pteraspis Banksii.
Pterygotus ludensis.	Onchus tennistriatus.

N.B. The following occur throughout the Silurian from the Llandovery to Ludlow.

Favosites gothlandica.	Atrypa reticularis.
Heliolites interstincta.	Strophomena euglypha.
Calymene Blumenbachii.	„ depressa.
Phacops caudata.	Orthis elegantula (lunata).
Proetus latifrons.	Rhynchonella Wilsoni.

DEVONIAN SYSTEM.

A. OLD RED SANDSTONE.

Lower O. R. S.

Pterygotus Anglicus.	Pteraspis Lloydii.
Cephalaspis Lyellii.	

Middle O. R. S.

Asterolepis Asmusii.	Diplacanthus gracilis.
Osteolepis major.	Phyllolepis concentricus.
Pterichthys major.	Glyptolepis elegans.

Upper O. R. S.

Cyclopteris Hibernica.	Coccosteus decipiens.
Cyclostigma minutum.	Holoptychius nobilissimus.
Anodonta Jukesii.	

B. DEVONIAN ROCKS.

Lower Devonian.

Alveolites suborbicularis.	Phacops laciniatus.
Homalonotus armatus.	Orthis arcuatus.

Middle Devonian.

Cyathophyllum cæspitosum.	Calceola sandalina (Goniophyllum).
Heliolites porosa.	Stringocephalus Burtini.

Favosites cervicornis.
Bronteus flabellifer.
Uncites gryphus.
Megalodon cucullatus.

UPPER DEVONIAN.

Phacops latifrons.
Cypridina serratostriata.
Spirifera disjuncta.
Cucullela Hardingii.
Clymenia linearis.
Goniatites subsulcatus.

CARBONIFEROUS SYSTEM.

CARBONIFEROUS SLATE AND LOWER LIMESTONE SHALE.

Spirifera cuspidata.
Rhynchonella pleurodon.
Streptorhyncus crenistria.
Modiola Macadami.
Cucullela Hardingii.
Ctenodonta tumida.

CARBONIFEROUS LIMESTONE.

Spirifera striata.
Terebratula sacculus.
Orthis resupinata.
Rhynchonella acuminata.
Lithostrotion junceum.
Michelinia favosa.
Platycrinus lævis.
Actinocrinus 30-dactylus.
Phillipsia pustulata.
Producta semireticulata.
Euomphalus pentangulatus.
Orodus ramosus, etc.

YOREDALE SERIES, MILLSTONE GRIT AND GANNISTER BEDS.

Lepidodendron Veltheimianum.
Aviculopecten papyraceus.
Posidonomya Becheri.
Producta scabricula.
Discina nitida.
Goniatites sphæricus.
„ Listeri, etc.
Orthoceras Steinhaueri.

COAL MEASURES.

Sigillaria reniformis.
Calamites Suckovii.
Lepidodendron Sternbergi.
Alethopteris lonchitica.
Neuropteris gigantea.
Spirorbis carbonarius.
Cythere inflata.
Anthracosia Phillipsii.
„ acuta, robusta, etc.
Megalichthys Hibberti.

PERMIAN SYSTEM.

Rothliegende and Lower Sandstone (England).

Callipteris conferta.	Unio tellinarius.
Walchia piniformis.	Palæoniscus Blanvillei.
Calamites gigas.	Acanthodes gracilis.

Kupfer Schiefer and Marl Slate.

Neuropteris Huttoniana.	Palæoniscus comptus.
Lingula mytiloides.	Cælacanthus granulatus.
Platysomus striatus.	Acrolepis Sedgwickii.

Zechstein and Magnesian Limestone.

Fenestella reteformis.	Avicula speluncaria.
Camaraphoria crumena.	Schizodus Schlotheimi.
Producta horrida.	Axinus obscurus.
Lingula Credneri.	Nautilus Frieslebeni.

Upper Sandstone.

Calamites arenaceus.	Lepidodendron elongatum.

TRIASSIC SYSTEM.

Bunter Sandstone.

Æthophyllum speciosum.	Nothosaurus Schimperi.
Voltzia heterophylla.	Cheirotherium Barthi.

Muschelkalk.

Terebratula vulgaris.	Ceratites nodosus.
Encrinus liliformis.	Nautilus hexagonalis.
Gervilia socialis.	Placodus gigas.

Keuper Marls.

Equisetites columnaris.	Labyrinthodon Jaegeri.
Estheria minuta.	Hyperodapedon Gordoni.

Rhætic Beds.

Avicula contorta.	Hybodus plicatilis.
Cardium rhæticum.	Saurichthys apicalis.
Pecten valoniensis.	Gyrolepis tenuistriatus.

JURASSIC SYSTEM.

LOWER LIAS.

Spirifer Walcottii.
Rhynchonella rimosa.
Extracrinus Briareus.
Gryphæa incurva.
Hippopodium ponderosum.
Belemnites elongatus.
Ammonites planorbis.
" Bucklandi.

MARLSTONE.

Terebratula punctata.
Rhynchonella tetrahedra.
Ammonites margaritatus.
" spinatus.

UPPER LIAS.

Rhynchonella cynocephala.
Leda ovum.
Belemnites tubularis.
Cardinia Listeri.
Ammonites bifrons.
" communis.

INFERIOR OOLITE.

Terebratula fimbria.
" perovalis.
Rhynchonella spinosa.
Collyrites ringens.
Astarte elegans.
Pholadomya fidicula.
Ammonites Murchisoniæ.
" Parkinsoni.
" Humphresianus.
Belemnites ellipticus.

GREAT OOLITE AND BRADFORD CLAY.

Terebratula digona.
Rhynchonella concinna.
Apiocrinus Parkinsoni.
Ceromya concentrica.
Trigonia Goldfussii.
Purpuroidea Morrisii.
Cylindrites acutus.
Patella rugosa.

CORNBRASH AND FOREST MARBLE.

Terebratula intermedia.
" lagenalis.
Avicula echinata.
Nucleolites clunicularis.
Acrosalenia hemicidaroides.
Holectypus depressus.

OXFORD CLAY.

Gryphæa dilatata.
Myacites recurva.
Trigonia costata.
Alaria composita.
Belemnites Puzozianus.
Ammonites Lamberti.
" cordatus.
" excavatus.

CORAL RAG (of England).

Thamnastrea arachnoides.
Thecosmilia annularis.
Cidaris florigemma.
Echinobrissus scutatus.
Chemnitzia Heddingtonensis.
Ammonites perarmatus.

CORALLIEN (of the Continent).

Terebratula moravica.	Astarte supra-corallina.
Cidaris florigemma.	Diceras arietina.
Hemicidaris crenularis.	Ammonites achilles.
Cardium corallinum.	" tenuilobus.

KIMMERIDGE CLAY.

Rhynchonella inconstans.	Patella latissima.
Exogyra virgula.	Ammonites biplex.
Thracia depressa.	" mutabilis.
Trigonia clavellata.	Pliosaurus.

PORTLAND BEDS.

Isastrea oblonga.	Trigonia gibbosa.
Lucina portlandica.	Cerithium portlandicum.

PURBECK BEDS.

Cycadeoidea microphylla.	Ostrea distorta.
Archæoniscus Edwardsii.	Lepidotus minor.
Cypridea tuberculata.	Pleurosterum ovatum.

ZONES OF THE LIAS.

Lower Lias.	Zone of	Ammonites	planorbis.
	"	"	angulatus.
	"	"	Bucklandi.
	"	"	semicostatus.
	"	"	obtusus.
	"	"	oxynotus.
	"	"	armatus.
	"	"	Jamesoni.
	"	"	ibex or Henleyi.
	"	"	capricornis.
Middle Lias.	"	"	margaritatus.
	"	"	spinatus.
Upper Lias. ..	"	"	communis.

ZONES OF THE INFERIOR OOLITE.

Zone of Ammonites jurensis.
" " Murchisoni.
" " Sowerbyi.
" " Humphresianus.
" " Parkinsoni.

ZONES OF THE OXFORD CLAY (OPPEL).

Zone of Ammonites macrocephalus.
" " anceps.
" " athleta.
" " biarmatus.
" " transversarius.

CRETACEOUS SYSTEM.

A. LOWER DIVISION.

WEALDEN.

Endogenites erosa.	Unio valdensis.
Lonchopteris Mantellii.	Paludina fluviorum.
Cypridea valdensis.	Iguanodon Mantelli.
Cyrena media.	Hylæosaurus, etc.

LOWER NEOCOMIAN (France and the Continent).

Pygurus rostratus.	Ostrea Couloni.
Echinospatagus cordiformis.	Belemnites latus.
Terebratula diphyoides.	Ammonites radiatus.

MIDDLE NEOCOMIAN (Tealby Series and Atherfield Clay).

Meyeria vectensis.	Trigonia caudata.
Terebratula sella.	Pectin cinctus.
Diceras Lonsdalei.	
Exogyra sinuata.	Ammonites Deshayesi.
Perna Mulleti.	Crioceras Duvallii.
Gervilia anceps.	Ancyloceras gigas.

URGO-APTIEN (of the Continent).

Orbitolites lenticulata.	Requienia ammonia.
Goniopygus peltatus.	Pteroceras pelagi.
Rhynchonella lata.	Ammonites Deshayesi.

UPPER NEOCOMIAN (Aptien and Folkestone beds, etc.).

Terebratula montoniana.	Panopea plicata.
Waldheimia psendojurensis.	Inoceramus Salamomi.
Rhynchonella Gibbsii.	Ammonites mammilaris.

B. UPPER DIVISION.

LOWER GAULT CLAYS (Albien).

Trochocyathus conulus.	Belemnites minimus.
Inoceramus concentricus.	Ammonites lautus.
Nucula pectinata.	,, auritus.
Aporrhais Parkinsoni.	,, interruptus.
Solarium ornatum.	Hamites intermedius.

Upper Gault and Upper Greensand (Vraconnien).

Terebratula biplicata.	Inoceramus sulcatus.
Terebratella pectita.	Pleurotomaria Rhodani.
Rhynchonella dimidiata.	Ostrea frons.
Holaster lævis.	Ammonites rostratus.
Pecten asper.	Hamites armatus.

Chalk Marl and Lower Chalk (Cenomanien).

Holaster subglobosus.	Belemnitella plena.
Terebratula semiglobosa.	Ammonites varians.
Lima globosa.	,, rhotomagensis.
Pecten Beaveri.	Turrilites costatus.

Middle Chalk (Turonien).

Ventriculites radiatus.	Rhynchonella Cuvieri.
Discoidea cylindrica.	Inoceramus labiatus.
Echinoconus subrotundus.	Ammonites peramplus.
Terebratulina gracilis.	Ptychodus decurrens.

Upper Chalk (Senonien).

Micraster cor-anguinum.	Lima Hoperi.
Echinoconus conicus.	Spondylus spinosus.
Ananchytes ovatus.	Parasmilia centralis.
Terebratula cornea.	Inoceramus Brongniartii.
Rhynchonella octoplicata.	Belemnitella mucronata.

Mæstricht Chalk (Danian).

Brachyurus rugosus.	Nautilus Danicus.
Hemipneustes radiatus.	Baculites Faujasii.

ZONES OF THE UPPER CRETACEOUS SERIES.

Gault and Upper Greensand.	Zone of Ammonites interruptus.
	,, ,, lautus.
	,, ,, rostratus.
	,, Pecten asper.
Lower Chalk.	,, Holaster subglobosus.
	,, Belemnites plenus.
Middle Chalk.	,, Rhynchonella Cuvieri.
	,, Terebratulina gracilis.
	,, Micraster breviporus.
	,, Holaster planus.
Upper Chalk.	,, Micraster cortestudinarium.
	,, ,, coranguinum.
	,, Belemnitella mucronata.

EOCENE SYSTEM.

THANET SANDS AND WOOLWICH BEDS.

Ostrea Bellovacina.	Cyprina Morrisii.
Cyrena cuneiformis.	Melania inguinata.
Corbula longirostris.	Cerithium funatum.

LONDON CLAY.

Nummulites planulata.	Rostellaria ampla.
Vermicularia Bognoriensis.	Voluta nodosa.
Zanthopsis tuberculata.	Nautilus centralis.
Pholadomya margaritacea.	Aturia ziczac.

BAGSHOT AND BRACKLESHAM BEDS.

Nummulites lævigata.	Conus deperditus.
Litharea Websteri.	Turritella imbricataria.
Cardita planicosta.	Cerithium giganteum.

BARTON CLAY.

Nummulites variolaria.	Conus dormitor.
Crassatella sulcata.	Voluta luctatrix.
Chama squamosa.	Pleurotoma colon.
Rostellaria rimosa.	Fusus longævus.

HEADON BEDS.

Cyrena obovata.	Limnea longiscata.
Cytherea incrassata.	Planorbis euomphalus.
Potamides concavum.	Melania muricata.

OSBORNE AND BEMBRIDGE SERIES.

Chara tuberculata.	Paludina lenta.
Bulimus ellipticus.	Planorbis discus.
Melanopsis carinata.	Melania turritissima.

EOCENE MAMMALIA.

Palæotherium magnum and minus.
Anoplotherium gracile and commune.
Dichobune cervinum.
Chæropotamus Cuvieri.
Coryphodon eocænus.

MIOCENE SYSTEM.

HEMPSTEAD BEDS (Lower Miocene).

Chara medicaginula.	Rissoa Chastelii.
Sequoia Couttsiæ.	Paludina lenta.
Corbula pisum.	Cerithium elegans.
Cyrena semistriata.	Voluta Rathieri.

LOWER MIOCENE PLANT BEDS (Bovey Tracey, etc.).

Sequoia Couttsiæ.	Corylus grosse-dentata.
,, Langsdorfii.	Cinnamomum lanceolatum.
Lastrea stiriaca.	Banksia longifolia.
Carpinus grandis.	Sabal major.

UPPER MIOCENE (Faluns of Touraine).

Scutella Faujasi.	Pleurotoma tuberculosa.
Voluta Lamberti.	Cardita Jouanneti.
,, rarispina.	Ostrea crassissima.
Turritella (Proto) cathedralis.	Lamna contortidens.

UPPER MIOCENE OF ŒNINGHEN.

Acer trilobatum.	Hakea salicina.
Smilax sagittifera.	Cinnamonum polymorphum.
Platanus aceroides.	Glyptostrobus europæus.

MIOCENE MAMMALIA.

Dinotherium giganteum.
Anthracotherium magnum.
Hyopotamus bovinus.
Acerotherium incisivum.
Mastodon augustidens.

PLIOCENE SYSTEM.

Note.—All the continental Pliocene deposits contain different assemblages of species, so that only those characteristic of the British Crags are given below. For fossils of foreign deposits, Lyell's Students' Manual may be consulted.

CORALLINE CRAG.

Flabellum Woodii.
Theonoa globosa.
Fascicularia aurantium.
Terebratula grandis.
Astarte Omalii.
Pecten opercularis.
Cardita senilis.
Voluta Lamberti.

RED CRAG.

Balanophyllia calyculus.
Cardium augustatum.
Pectunculus variabilis.
Fusus contrarius.
Nassa reticosa.
Purpura tetragona.

NORWICH CRAG.

Rhynchonella psittacea.
Tellina obliqua.
Astarte borealis.
Nucula Cobboldiæ.
Scalaria Grænlandica.
Natica helicoides.

PLIOCENE MAMMALIA.

Elephas meridionalis.
Mastodon arvernensis.
Balænodon emarginatus.
Tapirus priscus.
Cervus anoceros.
Rhinoceros leptorhinus.

PART V.

CHAPTER I.

FIELD GEOLOGY—ITS SCIENTIFIC AND PRACTICAL RESULTS.

Suggestions to the Student—Importance of Accuracy—Difficulties in certain cases.

THE object of all geological surveying is to determine, map out, and in every possible way to demonstrate the actual structure of a country; and this not only at its surface, but also to a great depth below. It is, in short, to formulate that which is known or can be ascertained of its geological structure, and to proceed from this towards that which is more or less hidden and obscure; every step in the former process being based upon evidence, and in the latter inferred from indication and from probability, which often amounts almost to certainty. Therefore it follows that, if our inferences are to be of any real value, accuracy in our methods and in our work, so far as such can be attained, is of the first importance. This has been urged throughout the preceding pages, although those cases have been excepted where an approximation to the truth is of equal service and much more easy of attainment.

The value of exact observation, and of careful records of what has been observed, is great as a contribution to the science of Geology. Other workers in the same field of research may draw conclusions from the results of our labours which we ourselves may overlook, or which may relate to their own special branch of the study, but which will be valueless if the data upon which they are based are not reliable. A habit of exact and careful work in the field is also of much benefit to other geologists, as well as to ourselves, in not only that views based upon correct observations are more certain to be sound, but that we see, record, and preserve facts which otherwise, although perceived at the time, may soon, amidst fresh scenes or subjects, be entirely forgotten.

Further, it is impossible for any one individual, however zealous or expert, to examine all areas for himself; therefore, if he would know the geology of a country, he must depend on the observations of others. From these, when accurate and trustworthy, he may formulate certain propositions, or even propound some grand generalisation, which, for all time, may be a source of pleasure or of profit to, or may tend to lighten the future labour of not only the observer upon whose work the propositions may be founded, but also the world at large.

Very important generalisations in geology have been made from scientific observation of the character and mode of occurrence of beds at distant points, bringing all apparently discordant features into one harmonious whole, with sometimes grand and unexpected results. As an example may be cited Professor Prestwich's arguments in favour of obtaining a supply of water for

London from the Lower Greensand.* These affirmed the probable existence of that water-bearing formation beneath the metropolis, and were based upon a study of the physical conditions of its outcrop many miles away from the point in question. The conclusions have been amply justified so far as the reasoning is concerned, and down to a certain point where abnormal conditions were found to prevail, which could not have been predicted from a survey confined to the outcrop of the Lower Greensand and overlying formations. Although the Lower Greensand has not been met with under London, it is owing to what may be called an accidental circumstance, which has given rise to another important question—the occurrence or non-occurrence of coal in the South of England.

The underground extension of a ridge of Palæozoic rocks was proved by a deep boring at Kentish Town, of sufficient height to reach the Gault, and thus to cut out the Lower Greensand, that otherwise must have been there.† For the Secondary rocks were, of course, originally deposited in a fairly level position, and in the London area have not since been subjected to much disturbance. They should consequently be found, when not thinned out, in regular sequence; but if a tract of high ground existed in the area of their deposition, the beds must now abut on the flanks of such elevation.

Mr. Godwin-Austen, in another grand generalisation, based upon ascertained facts and logical inferences, has

* 'Water-bearing Strata of the London Basin,' 1851.

† 'Account of the Kentish-town Well-section.' Prestwich: 'Quarterly Journal Geological Society,' vol. xii. p. 9.

drawn attention to the fact that if such high ground consists of the lower part of any series, the upper members should also be found on either flank, with their denuded edges covered by the newer formations. And therefore, if the rock underlying the Gault beneath London has since been proved to be Old Red Sandstone, then the Coal-measures, the New Red Sandstone, etc., must occur on either side of the anticlinal that has brought it up to that position. That, in fact, the ridge beneath London is part of an extension of the South Wales anticlinal to that of Belgium; therefore the Coal-measures worked in those areas must also occur on each flank, and would probably be found, as in those areas, at a moderate depth, unless removed by an ancient denudation.

The geologist having, by careful collection and accurate observation of all available data, attained to a knowledge of the geology of a district, and, viewing the whole tract at once, as upon a map, can in his mind lift up formation after formation, and see those beneath as plainly as though they had never been covered. In imagination removing one series of deposits, he sees beneath it the surface of another, which may or may not have been eroded previous to the deposition of the one thus removed. If it has not, he views its full extension, marks its gradually thinning boundaries, defined probably by lines of cliffs and of conglomerates, the ancient beaches; if denuded, he sees the exposed edges of the eroded strata, cut through by ancient valleys, and in places outliers only remaining to mark its former extension. Some parts of the old surface may be covered by sheets of lava, intersected by volcanic dykes, or

perhaps dislocated by faults in every direction. He notes also the gradual approach of those variations in the conditions of climate, land, and sea which ultimately lead to the deposition of the succeeding formation, and which drive before them, slowly but inevitably, the existing forms of life, and bring in new races of inhabitants.

When the mind has grasped these facts, some supported, it may be, by strongest evidence, others rendered clear by scientific induction, the aim and end of our geological research has been mainly achieved. We cannot always hope to carry our deductions to the extent here indicated, but it may be done with a fair probability of accuracy within reasonable limits. And it is in the employment of this kind of knowledge that geology looks for its practical result, in the assistance that it is enabled to afford in mining, engineering, quarrying, and well-boring operations, although it cannot be denied that scientific results, apart from practical considerations, also present by themselves a very great attraction.

As an example of geological work possessing a high degree of both scientific and practical value, because it is, within reasonable limits, accurate, although based to a great extent upon inference, may be mentioned the Horizontal Sections published by H.M. Geological Survey. The evidence from which these sections are drawn (sometimes obscure even at the surface, and frequently scanty for all below) is collected during the survey of the area across which they run. It consists of the outcropping edges of the formations, and of all natural and artificial sections that can be obtained along or near to their course. The beds are drawn throughout by con-

necting them between the points where thus examined, and by downward extension—not directly, but with due allowance for intermediate changing dip, changing strike, throw of faults, springs, varying thickness calculated from surface evidence, and so on. These sections are filled in, sometimes for miles, without any real evidence but that of the outcrop of the beds, yet they show them several hundreds of feet beneath the surface, and are but rarely found to present more than trifling inaccuracies. It need scarcely be added that for the purposes of mining, in which large sums of money can be readily wasted, and of Artesian wells, and other deep borings, they are simply invaluable.*

It may not be always possible to make a strictly accurate geological survey—indeed, it frequently happens that the indications upon which the geologist relies, especially when sections are scarce, are so obscure and puzzling that he cannot satisfy himself in the drawing of his lines, or even in the interpretation of the evidence he has been able to glean. In these cases it is well to leave the boundary lines for awhile, and to work up to them from a different direction to that which has hitherto been followed. If still difficult to decipher, it would lead one to suspect the presence of a fault by which the beds have been displaced, of intrusive or eruptive igneous masses, or of unlooked-for drift deposits. Any or all of these may be reasonably expected to occur; but a little patience in traversing, the lines being for the time disregarded, will generally be rewarded by the discovery of some piece of evidence by which the character of the change, or the cause of the difficulty,

* See *ante*, p. 263.

may be revealed. This plan involves a second visit to the area in question, but time will nevertheless be saved by the skimming over an obscure portion, and working back over it from a point where the rocks and their relation to each other are clear, towards the part where the difficult ground began.

Again, it is not at all times easy to distinguish, in districts where slaty rocks occur, the true bedding-planes from those of cleavage. The latter are sometimes observable in limestones and sandstones, and even in some trap-rocks, but are most apparent in clay-slates, and are generally 'nearly coincident with the strike of the bed,' (*Sedgwick*). The joints usually found in the coarser slates will help to determine the planes of the bedding, to which they are at right angles, or, at all events, oblique. Alternations with other beds will be a sure guide where they can be seen in section, or their outcrop followed. But where the slates of finer texture, such as those used for roofing, occupy large tracts and in great thickness, it may be extremely difficult to discover the true lines of stratification.

'Bands of colour, such as faint red, green, white, or grey, may sometimes be observed on the sides of slates, often coinciding with slight changes of grain or texture. These, which are called the "stripe" of the slate by Professor Sedgwick, mark its original stratification. Irregular blotches, however, of different colours, occasionally occur; and sometimes even pretty regular broad bands of colour are to be seen, which do not coincide with the bedding, but go sometimes directly across it, as proved by beds of sandstone interstratified with the slate. Care must be taken, therefore, in field observations, not to rely too implicitly on mere bands of colour in slate-rocks, unless they coincide with bands of various texture—that is, layers of

finer and coarser grain, which may always be trusted to show the original "layers of deposition" in the rock.' *

In North Wales the trap-rocks, with their associated ashes, have been affected to such an extent by cleavage that there is great difficulty in separating the one from the other.† Besides such stratigraphical perplexities, the student will also, in certain cases, meet with those of a lithological nature, as, for instance. in the district just referred to, it is almost impossible to say which of the characters of the altered ashes are, and which are not, due to the action of metamorphic agencies.

'The identification of very old deposits of volcanic ash is not always an easy task. Where numerous lapilli of scoriaceous and other unquestionably eruptive rock occur in old indurated ashes, it is comparatively easy to recognise the origin of the deposits; but when these fail, it becomes a matter of considerable difficulty to say with any certainty whether a rock formed of broken crystals, such as might characterise any lava, in conjunction with very finely divided matter, such as might be referred either to fine volcanic dust or to ordinary detrital sediment, really represents a volcanic ash, or is simply a sediment wholly or partly of the detritus of pre-existing eruptive rocks.' ‡

In such difficult cases, which are, however, exceptional, the best plan to pursue is to assiduously collect all obtainable evidence of a stratigraphical nature, and to submit specimens of doubtful rocks to a micro-petrologist for examination and identification. And in the

* Jukes' 'Manual of Geology,' 1872, p. 221 (A. and C. Black).

† Mems. Geological Survey, 'North Wales' (Ramsay), p. 120.

‡ 'The Study of Rocks,' p. 268: Rutley (Longmans and Co.), 1879.

absence of evidence from sections, the natural features of the country must be especially observed; indeed, the value of a study of the 'shape of the ground' at all times, not on the larger scale only, but in all its minor details, cannot be too strongly affirmed. For, the physical features of a country being directly due to those which are geological, such study will certainly afford a clue to, if it will not establish, the run of the rocks and their mutual relations. The softest rocks, and those which from other peculiarities are most readily denuded, will, *cæteris paribus*, be the first worn down into valleys; and this not at one point only, but generally along their strike. Dip, as we have seen, interferes with such a simple mode of denudation; therefore, in studying the form of the ground, the geologist must have in his mind the probability of its being due to one or the other, or to both, of the phenomena. Any minor features that may be observed will then help him to decide, at once and almost with certainty, what share and which actual portion of the work performed by the denuding agencies must be due to each, and thus to arrive at reliable conclusions regarding the stratigraphical geology. Such minor features are numerous, the most usual being sudden local changes in slope, springs—especially when in lines or in any number—and swallow-holes, which point to exactly the same geological conditions, although they are the reverse of springs, in that they carry water away from the surface, but only to throw it out again as springs elsewhere.

CHAPTER II.

FIELD GEOLOGY—ITS SCIENTIFIC AND PRACTICAL RESULTS (*continued*).

Springs — Artesian Wells — Water Supply — Denudation — Escarpments—Ancient Valleys—Scenery.

THE importance of Field Geology, whether as a science or an art, or as a combination of science and art, need not here be insisted on, nor can its practical value be even approximately estimated. It may, however, be safely asserted that the influence of geological conditions is universal, as by these all lands are affected, being remodelled by the agencies with which geology deals—all seas, as they are modified by the action of the laws which it expounds—all races of plants and animals, even including Man himself, the varieties of conditions suited to their existence being dependent upon geological phenomena. What is true of the earth as a whole, and of all its occupants, must be equally true of localities and individuals; and the influence of the geology of a country upon its characteristic features, its producing power, and its inhabitants, must be co-extensive with the country itself, and therefore worthy of thorough, trained investigation.

The most direct practical result of field geology is the impetus it is enabled to give to the productiveness

of any district scientifically explored, by indicating its sources of mineral wealth, and guiding the miner and the capitalist to the hidden stores of Nature. Next in importance, perhaps, is the producing power of its soils which are directly dependent on the nature of the rocks from which they have been formed; succeeded in order by that of the information field geology affords relating to the sources of pure water from deep-seated springs, which, in thickly-peopled areas, is one of the first necessities of their population. The methodical utilisation of its building materials, the discovery of native fertilising productions, the indication of sites best suited from all points of view—sanitary, economical, and artistic—to its engineering, public, and domestic works, are also important matters with which field geology is concerned.*

The methods employed in discovering, surveying, and recording all the native productions are described in the preceding pages, and the chief characteristics by which engineering, building, and sanitary works are affected. Allusion only has been made to those peculiarities by which the supply of water from natural springs is influenced; therefore a few notes are appended upon the nature of springs, their modes of occurrence, and the means employed for their utilisation.

The phenomena of springs of all kinds—whether deep-seated, surface, or overflowing, intermittent or perennial—are entirely dependent on the nature and relations of the rocks of a district, their position being governed by its physical features. As the rocks are

* See 'Engineering Geology,' by the Author. Baillière and Co.

pervious or impervious, so the water passes through or is upheld by them; according to their relative levels it is absorbed by the pervious strata, or thrown out from them as springs; and as upheaval or denudation has altered the shape of a country, so the springs which overflow have changed their position, their occurrence, indeed, having been one of the agents in the gradual sculpturing of the ground.

The subject may be advantageously divided into three sections:

1. Origin of the supply.
2. Springs and streams. (*Natural founts.*)
3. Wells. (*Artificial founts.*)

1. *Origin of the supply.*—The original source whence is derived all our supply of water—whether it come to our hand through natural or artificial founts—is, of course, the 'Rainfall.' This may vary somewhat in annual amount, and be much greater in some localities than in others, but is always and everywhere in these islands, with rare exceptions, much in excess of what is actually necessary to the population.

The minimum Rainfall is about 25 inches; the average is about 34 inches. In dry years (in some localities) it has been but 16 inches; in wet years (in other localities) it has been even as high as 20 feet.*

The average daily quantity required for each head

* This excessive rainfall occurred in the Lake District, in 1872; in the Southern and Eastern counties, in the same year, it was 27 inches. The rainfall of 1872 was 36 per cent. above, and of 1870, 18 per cent. below, the average.

> of the population is 30 gallons, or 50 tons per year. One inch of rainfall on an acre of land is equal to 100 tons, and there are 1½ acres to each head of population.

Therefore a quantity equal to a rainfall of only one-third of an inch is sufficient for the requirements of the population.

A very large portion of the rainfall runs away in rivers to the sea; another is given back to the atmosphere by evaporation. But in every year and in every locality there remains, as stated above, a quantity which, economised and utilised, would be much in excess of our requirements. And this quantity finds its way into the hidden recesses of the earth, to be given, or drawn, forth from the natural and artificial founts described in the following sections. Then, it may be asked, 'How is it that our supply should ever be unequal to the demand?' The answer is simple:—We do not economise that to be derived from the natural founts, and we do not sufficiently avail ourselves of the artificial founts, which are at all seasons practically inexhaustible.

In proportion to the size of the collecting area—that is, the outcrop of the permeable strata beneath any district—will be the quantity, and according to the nature of the strata through which it passes will be the quality, of the water supplied.

2. *Streams and Springs.*—The water supply of any particular district is not, by any means, necessarily proportionate to its rainfall, as much depends upon its physical geography, its height above the sea, and especially upon the nature of its soils, subsoils, and underlying strata. So far as natural founts are concerned,

the inhabitants of the valleys will be better off than those of the hills, and of the low-lying districts than those of greater elevations. The permeable strata retain a large quantity of the rain which falls upon them, as it is drawn by the law of gravitation to a lower level; whereas, if the surface be impervious, all the water runs off by the ditches and rivulets to the larger rivers, and thence to the sea. Whether the surface be wholly or partly pervious, a large portion runs to the rivers; but much is absorbed by the water-bearing strata, and again thrown out at a lower level, in the form of springs, on the hill-sides; or, the conditions being favourable, it is retained by those strata at various depths, which thus are constituted huge underground reservoirs.

The strata that now throw out springs would, if occurring at a different level, or if inclined at a suitable angle, become the means of draining water from the surface, the springs of one locality being, in fact, but natural outlets for the drainage of another.

The supply from the natural founts will vary as the seasons: in periods of drought the streams run dry and the springs fall off, while shallow wells, which derive their water either by soakage from a stream or from a so-called land-spring, become exhausted in consequence. Neither streams nor surface-springs should be depended on for a constant supply of pure water, not only on account of their intermittent nature, but because of their liability to pollution.

3. *Wells.*—This part of the subject consists of a utilisation of the 'theory of springs,' in their relation to Artesian wells or deep borings, and it may be illustrated by performing in imagination a simple experiment.

Take two shallow dishes, and place one on the other with a layer of sand between them; pour in water at one edge of this layer, and it will be found that in a very short time the sand is saturated alike throughout. The water has, in fact, first descended by gravitation under the upper dish, then risen, through the force of hydrostatic pressure, to the other edge of the sand, and to the same level as that at which it entered. If a hole be bored through any part of the upper dish, the water will rise in that hole until it stands at the same level; and if the upper dish were filled with clay or any other impervious material, the water would, of course, rise in the hole in a similar manner.

Here are all the phenomena of deep-seated springs and Artesian wells; for what occurs on a small scale in the sand confined between the dishes, occurs in nature in pervious strata confined between those that are impervious, the water rising in the hole representing exactly what happens in an Artesian well. The water bearing bed may not be absolutely continuous, but the same results will follow so far as the continuity be unbroken, and the water will always rise to what is its normal water-level. There may be natural outlets at a lower level than the outcrop of the pervious beds, when perennial springs are the result; but these springs affect the main supply to the well in the same proportion only as the discharge from them bears to the amount of rainfall upon the outcrop.

It follows that, when all the conditions of dip, permeability, and continuity are known, it becomes a matter not of speculation, but of certainty, to estimate the depth at which water will be found, and the height to

which it will rise in the well. Also that the water supply of a district is not by any means proportionate to its own rainfall; for the water-bearing beds are great distributors, and by them the supply is to a great extent equalised.

When a boring is made at a place situated at a lower level than that of the outcrop of the water-bearing stratum, the water rises above the surface. This is the case at several deep wells in the valley of the Lea, sunk down to beds of sand and pebbles which come to the surface at a higher level several miles to the northward, and at many others through the Gault into the Lower Greensand, in the neighbourhood of Cambridge.* The supply to be obtained by boring down to deep-seated springs is practically inexhaustible, being scarcely, if at all, affected by drought, and these springs form the only source on which can be placed a full reliance.

In investigating the physical and geological features by which the existing or possible water supply of any district is governed, the size of the collecting area (which may be near or distant), and the nature and relative positions of the rocks through which the water must flow, are first considered: these affect the quantity and quality of the water available. Water may frequently be found on the upper side of a fault—not necessarily the upthrow side, but that side on which the beds have a general dip towards it—by which a pervious stratum is faulted against one that is impervious and arrests the water in its downward passage. Then the thickness of the rocks, or rather the depth to the water

* 'The Geology of Cambridgeshire:' Mems. Geological Survey. (In the press.)

bearing beds, at the spot in question, with the height to which the water from them will rise in a well or boring at a given elevation, must be ascertained. Such investigations are carried on by similar methods to those described in the earlier parts of this work; indeed, they form an important branch of geological surveying. (For more detailed remarks on springs, water-level, and water supply generally, also for simple directions for testing the quality and hardness of waters, see 'Engineering Geology,' Baillière and Co.)

The preceding references to the physical features of a district, by which its water supply is affected, may be appropriately supplemented by a few brief remarks upon the features themselves, and upon those of a geological nature with which they are associated. The denuding agencies, by which physical features have been formed, are explained in all geological manuals; but there are certain phenomena which the student of field geology may be expected occasionally to meet with that are not usually described.

Physical features frequently coincide with geological boundary lines. This is evident from a consideration of the first proposition on page 23; but strata are seldom seen in a really horizontal position—indeed, they are apt to be found (especially in the case of the more plastic rocks) rising at their outcrop, although perfectly level on the large scale, as proved by sections drawn across the area which they occupy. This slight bending up to the surface may extend along the whole length of the outcrop of otherwise level strata—a circumstance possibly owing to slight molecular expansion as the

weight of the rocks by which they were previously covered was removed by some process of denudation.

A good illustration of physical features coinciding with geological boundaries is afforded by the Lincolnshire 'Cliff,' an escarpment of the Upper Lias Clay, which, for a distance of seventy or eighty miles, is capped, but very thinly, by the base of the Lower Oolites. For many miles also, at the western margin of the same county, the river Trent follows, with slight exceptions caused by local irregularities and other causes, the line of division between the Triassic rocks and the Lower beds of the Lias.

Physical features almost invariably indicate the dip of the beds. Taking escarpments as an illustration, it will be seen that their present position may be due to the following set of conditions and agencies. Where an easily denuded formation, such as a clay, beneath harder rocks, would be intersected by a plane rising gently from the sea, a plain at the foot of an escarpment of the harder rocks would eventually be formed. The harder rocks were formerly cut through by rivers or streams along the strike of beds exposed by an anticlinal ridge, or rather an anticline which would have formed a ridge, but that the land-surface, at a period anterior to the formation of the English escarpments, was nearly level, having been formed, as demonstrated by Professor Ramsay, as a plain of marine denudation.* It may even

* 'Physical Geology and Geography of Great Britain' (Stanford). See also a valuable paper, proving the subaërial (as opposed to marine) origin of escarpments, on 'Subaërial Denudation,' by W. Whitaker, in the 'Geological Magazine,' vol. iv. p. 447—483.

have been (as it has in many instances) that the beds were first cut through across their strike, and more or less in the direction of their dip. But when once the underlying softer rock was reached, the denudation would proceed much more rapidly along its strike, and in that position form the principal valley, and eventually a plain, at the foot of an escarpment. Such a plain is thus dependent on the strike of the softer rock, which it follows, nearly but not quite, as it must always slope in a greater or less degree towards its outlet to a larger valley or to the sea. The dip, of course, varies with the strike; therefore, unless there be an unconformity between the two sets of rocks, the escarpment varies as the dip, and, inversely, the dip as the escarpment. It follows that the general line of the hill corresponds to the strike of its beds, which therefore may be assumed, in the absence of evidence to the contrary, to dip directly into the face of the escarpment. (See Prop. 2, p. 24.)

If this proposition regarding the origin of escarpments be correct, they can never recede beyond a definite point (which many have already reached) while the relative levels of land and sea remain unaltered. And it explains why some escarpments are straight and others curvilinear: their lines must correspond generally to the straight or curved strike of the rocks at their base, which, except in cases of unconformity, is also the strike of the rocks forming the escarpment.

River-courses are continually changing their position. Old and recent river-deposits are found in all valleys, at varying heights above and distances from the present streams; the different levels representing separate stages of the excavation of the valley, and their position away

from the stream, old courses more or less distant from those which they now occupy. There is a definite arrangement about these fluviatile deposits, all of them at or about the same level following straight or curved lines corresponding, or nearly so, with the stream-course at that elevation. And these old courses not only meander about in every direction along and across the present valley, but are sometimes clearly traceable over, or through some gap in, ridges which now divide the waters of totally distinct river-systems. The old deposits, by which they are represented, were formed during the earlier stages of some ancient river at a time when it ran, perhaps, directly across the strike of the rocks, but which was afterwards deflected by the circumstance of the ground having been more rapidly excavated along an anticlinal ridge or the outcrop of some easily-denuded formation.

Nearly all large valleys contain evidences of their ancient river-courses, away from and even cutting across that of the present rivers, as, for instance, that of the River Cam, in Cambridgeshire.* And, as a notable instance of an old river which formerly occupied ground now formed into two distinct valleys, may be mentioned the Trent, which at present flows nearly due north to the Humber, and is confined to the western side of the Lincolnshire Cliff, previously referred to as an instance of physical features now coinciding with geological boundaries. This river, in its earlier stages, ran directly across the present high ground, and by the Witham valley to the sea, cutting a steep gorge through the cliff

* 'The Geology of Cambridgeshire:' Mems. Geological Survey. (In the press.)

at Lincoln, there over 200 feet in height, and through which runs the River Witham, an old tributary of the Trent which thus far flows at the foot of the escarpment.*

As a rule, these old gravels, which contain prehistoric human relics and the remains of extinct mammalia, are not continuous, but occur in lines of small and usually elongated patches, capping mounds and ridges, and more rarely banked against the flanks of existing hills. It is evident that they were not deposited in such positions, so far, at least, as the mounds and ridges are concerned, but that the line of ground they cover was a valley at the time of their deposition. The patches, therefore, rest in old hollows or depressions, which give to their lower layers a synclinal form that has, in a great measure, contributed to their preservation, while the surrounding ground, formerly higher than that which they occupy, has been removed by denuding agencies. This trough-like form of section in these gravels has a bearing upon their water-yielding capacity: all the water within them, at a lower level than their boundary, is retained, but it would otherwise be thrown out along the margin, and it forms the source of supply to the surface-springs upon which many of the smaller towns and villages depend.

Those who would pursue the interesting subject of the connection between physical geology and landscape or scenery may peruse with much pleasure and advantage Professor Ramsay's 'Physical Geology and Geography

* A paper, by the Author, upon this subject is in course of preparation, and at an early date will be submitted to the Geological Society of London.

of Great Britain,' and a paper, by H. B. Woodward, in the 'Popular Science Review' for January, 1875, upon 'The Origin of English Scenery.' The field geologist cannot fail to be struck with the great diversity of physical features he will meet with in carrying on his researches, features which he knows to be due to the ceaseless action of geological agencies. And thus he is led to see that his science has not only its scientific and practical results, but those of artistic nature also, in the light it throws upon the origin of scenery, and the consequent additional charm it confers upon the study or delineation of the works of Nature.

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THE END.

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